CHAPTER IV — SUMMARY OF TROPICAL CYCLONES

1. WESTERN NORTH PACIFIC TROPICAL CYCLONES

During 1977, the western North Pacific experienced the smallest number of typhoons since JTWC's formation in 1959. Of the 21 numbered tropical cyclones occurring during 1977 (Table 4-1), only eleven developed to mature typhoons, eight peaked out as tropical storms, and two did not develop beyond depression stages. Tables 4-2 and 4-3 show that both the number of tropical storms and typhoons were well below the quantity normally observed. During the season, only Babe reached the 130 kt (67 m/sec) intensity necessary to be classified as a "super" typhoon. The months, January through June, were completely void of typhoons and had only a total of two tropical storms, Patsy in March and Ruth in June. This early season lull in activity was similar to that observed during 1973 and 1975. Tropical cyclone occurrences were near normal during July, but fell to a record low for August when no typhoons and only a single tropical storm was observed. During late July the southwest monsoon of India and Southeast Asia became very deep and intense, extended anomalously into the western North Pacific, and persisted for weeks. The monsoon trough was oriented in an east-northeast to west-southwest direction from Hainan Island to the Bonin Islands. Several cyclonic eddies formed within the trough as Monsoon Depressions, i.e., systems characterized by broad surface circulation centers, highly asymmetric wind fields, surface winds less than 34 kt (18 m/sec), greatest intensity at 5,000 to 10,000 ft (1470-2940 m), and strong vertical shear.

TABLE 4-1.
1977 TROPICAL CYCLONES

PACIFIC AREA

CYCLONE	TYPE	NAME	PRD OF WRNG	CALENDAR DAYS OF WARNING	MAX SFC WIND	MIN OBS SLP	NO. OF WARNINGS TOTAL	NO. OF WARNINGS AS TY	DISTANCE TRAVELLED
01	TS	PATSY	23 MAR-31 MAR	9	50	981	25	--	1190
02	TD	TD 02	26 MAY-27 MAY	2	30	1001	6	--	318
03	TS	RUTH	14 JUN-17 JUN	4	60	980	14	--	874
04	TD	TD 04	05 JUL-06 JUL	2	30	995	6	--	396
05	TY	SARAH	16 JUL-21 JUL	6	75	970	21	3	1548
06	TY	THELMA	21 JUL-26 JUL	6	85	957	21	11	1092
07	TY	VERA	28 JUL-01 AUG	5	110	926	18	13	814
08	TS	WANDA	31 JUL-04 AUG	5	45	986	17	--	936
09	TS	AMY	20 AUG-23 AUG	4	40	990	16	--	936
10	STY	BABE	02 SEP-10 SEP	9	130	906	36	20	2436
11	TS	CARLA	03 SEP-05 SEP	3	35	994	9	--	614
12	TY	DINAH	14 SEP-23 SEP	10	75	964	38	10	1998
13	TS	EMMA	15 SEP-20 SEP	6	60	966	21	--	1680
14	TS	FREDA	23 SEP-25 SEP	3	55	997	9	--	859
15	TY	GILDA	03 OCT-10 OCT	8	70	968	30	8	2332
16	TS	HARRIET	16 OCT-20 OCT	5	55	984	19	--	1544
17	TY	IVY	21 OCT-27 OCT	7	90	945	24	12	1877
18	TY	JEAN	*	6	65	972	20	3	1015
19	TY	KIM	06 NOV-17 NOV	12	125	916	44	25	1338
20	TY	LUCY	28 NOV-07 DEC	10	115	919	39	16	3922
21	TY	MARY	20 DEC-03 JAN	15	100	947	59	15	4002
			1977 TOTALS	124**			492	136	

INDIAN OCEAN AREA

CYCLONE	TYPE	NAME	PRD OF WRNG	CALENDAR DAYS OF WARNING	MAX SFC WIND	MIN OBS SLP	NO. OF WARNINGS TOTAL	NO. OF WARNINGS AS TY	DISTANCE TRAVELLED
	TC	17-77	11 MAY-13 MAY	3	60	980	4	--	374
	TC	18-77	10 JUN-13 JUN	4	60	985	6	--	510
	TC	19-77	29 OCT-31 OCT	3	40	994	5	--	691
	TC	21-77	*	11	70	979	19	4	1387
	TC	22-77	15 NOV-19 NOV	5	115	930	10	8	875
			1977 TOTALS	21**			44	12	

*JEAN 28 OCT-31 OCT AND 02 NOV-03 NOV
21-77 10 NOV-12 NOV AND 14 NOV-21 NOV

**OVERLAPPING DAYS INCLUDED ONLY ONCE IN SUM

TABLE 4-2 FREQUENCY OF TROPICAL STORMS AND TYPHOONS BY MONTH AND YEAR

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
AVERAGE (1945-58)	0.4	0.1	0.4	0.5	0.8	1.3	3.0	3.9	4.1	3.3	2.7	1.1	22.0
1959	0	1	1	1	0	0	3	6	6	4	2	2	26
1960	0	0	0	1	1	3	3	10	3	4	1	1	27
1961	1	1	1	1	3	2	5	4	6	5	1	1	31
1962	0	1	0	1	2	0	6	7	3	5	3	2	30
1963	0	0	0	1	1	3	4	3	5	5	0	3	25
1964	0	0	0	0	2	2	7	9	7	6	6	1	40
1965	2	2	1	1	2	3	5	6	7	2	2	1	34
1966	0	0	0	1	2	1	5	8	7	3	2	1	30
1967	1	0	2	1	1	1	6	8	7	4	3	1	35
1968	0	0	0	1	1	1	3	8	3	6	4	0	27
1969	1	0	1	1	0	0	3	4	3	3	2	1	19
1970	0	1	0	0	0	2	2	6	4	5	4	0	24
1971	1	0	1	3	4	2	8	4	6	4	2	0	35
1972	1	0	0	0	1	3	6	5	4	5	2	3	30
1973	0	0	0	0	0	0	7	5	2	4	3	0	21
1974	1	0	1	1	1	4	4	5	5	4	4	2	32
1975	1	0	0	0	0	0	2	4	5	5	3	0	20
1976	1	1	0	2	2	2	4	4	5	1	1	2	25
1977	0	0	1	0	0	1	4	1	5	4	2	1	19
AVERAGE (1959-77)	0.5	0.4	0.4	0.8	1.2	1.6	4.6	5.6	4.9	4.2	2.5	1.2	27.9

TABLE 4-3 FREQUENCY OF TYPHOONS BY MONTH AND YEAR

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
AVERAGE (1945-58)	0.4	0.1	0.3	0.4	0.7	1.1	2.0	2.9	3.2	2.4	2.0	0.9	16.3
1959	0	0	0	1	0	0	1	5	3	3	2	1	20
1960	0	0	0	1	0	2	2	8	0	4	1	1	19
1961	0	0	1	0	2	1	3	3	5	3	1	1	20
1962	0	0	0	1	2	0	5	7	2	4	3	0	24
1963	0	0	0	1	1	2	3	3	3	4	0	2	19
1964	0	0	0	0	2	2	6	3	5	3	4	1	26
1965	1	0	0	1	2	2	4	3	5	2	1	0	21
1966	0	0	0	1	2	1	3	6	4	2	0	1	20
1967	0	0	1	1	0	1	3	4	4	3	3	0	20
1968	0	0	0	1	1	1	1	4	3	5	4	0	20
1969	1	0	0	1	0	0	2	3	2	3	1	0	13
1970	0	1	0	0	0	1	0	4	2	3	1	0	12
1971	0	0	0	3	1	2	6	3	5	3	1	0	24
1972	1	0	0	0	1	1	4	4	3	4	2	2	22
1973	0	0	0	0	0	0	4	2	2	4	0	0	12
1974	0	0	0	0	1	2	1	2	3	4	2	0	15
1975	1	0	0	0	0	0	1	3	4	3	2	0	14
1976	1	0	0	1	2	2	2	1	4	1	1	0	15
1977	0	0	0	0	0	0	3	0	2	3	2	1	11
AVERAGE (1959-77)	0.3	0.1	0.1	0.7	0.9	1.1	2.8	3.6	3.2	3.2	1.6	0.5	18.3

Upon relaxation of the deep, southwest monsoon flow, Tropical Storm Wilda developed, but did not exceed 45 kt (23 m/sec) intensity in the environment of strong vertical shear. As Wilda moved east of Japan, she caused the monsoonal flow over the western Pacific to move toward the north, rather than toward the climatologically favored regions where tropical cyclones normally develop. This northward flow toward low pressure continued as several extratropical systems developed near the sea of Japan, south of the normal regions for extratropical cyclogenesis in August. About the middle of August, the deep, southwest monsoon flow again intensified, and again several Monsoon Depressions formed. When the monsoon finally weakened, Tropical Storm Amy developed, but barely to 40 kt (21 m/sec). Amy again drew the western Pacific region of low pressure far north of its normal position, preventing establishment of a significant near-equatorial trough (NET). In fact, during much of August, pressures were much above normal in the tropics and easterly winds dominated the equatorial regions, helping to prevent cyclogenesis. By early September, pressures had fallen in the tropics, flow was back to normal, and Super Typhoon Babe developed in the NET, south of Guam. The remainder of the 1977 season for both tropical storms and typhoons was near normal.

During 1977, 26 Tropical Cyclone Formation Alerts were issued. Of these, 20 or 77% developed into significant tropical cyclones (Table 4-4). No formation alert was issued for Typhoon Jean. Instead, a warning was issued in order to provide more information to a U. S. Navy ship approaching the system. The average lead time between issuance of a Tropical Cyclone Formation Alert and the first warning was 21 hours, with a minimum of 4 hours with Tropical Storm Wanda and a maximum of 48 hours with Typhoon Kim.

Only 12 multiple-storm days occurred in 1977 (Table 4-5). This is the lowest number of multiple-storm days observed since JTWC began keeping records in 1959. Like 1970 and 1975, there were no days in 1977 in which three or more western North Pacific tropical cyclones occurred simultaneously.

The 1977 tropical cyclone season was characterized by an abundance of poorly defined cyclones of relatively small radial extent of which many exhibited numerous erratic movements. The weaker cyclones were often inhibited from development by an unusually large and intense subtropical ridge and shear of the horizontal winds with height. In contrast, periods of weak steering currents resulted in five storms executing one or more loops each. Overall losses of life and property were thankfully small. Taiwan, however, survived a three-month drought, then experienced two of the worst typhoons in 80 years, Vera and Thelma.

TABLE 4-4.

PACIFIC AREA
TROPICAL CYCLONE FORMATION ALERT SUMMARY

YEAR	NUMBER OF ALERT SYSTEMS	ALERT SYSTEMS WHICH BECAME NUMBERED TROPICAL CYCLONES	TOTAL NUMBERED TROPICAL CYCLONES	DEVELOPMENT RATE
1972	41	29	32	71%
1973	26	22	23	85%
1974	35	30	36	86%
1975	34	25	25	74%
1976	34	25	25	74%
1977	26	20	21	77%

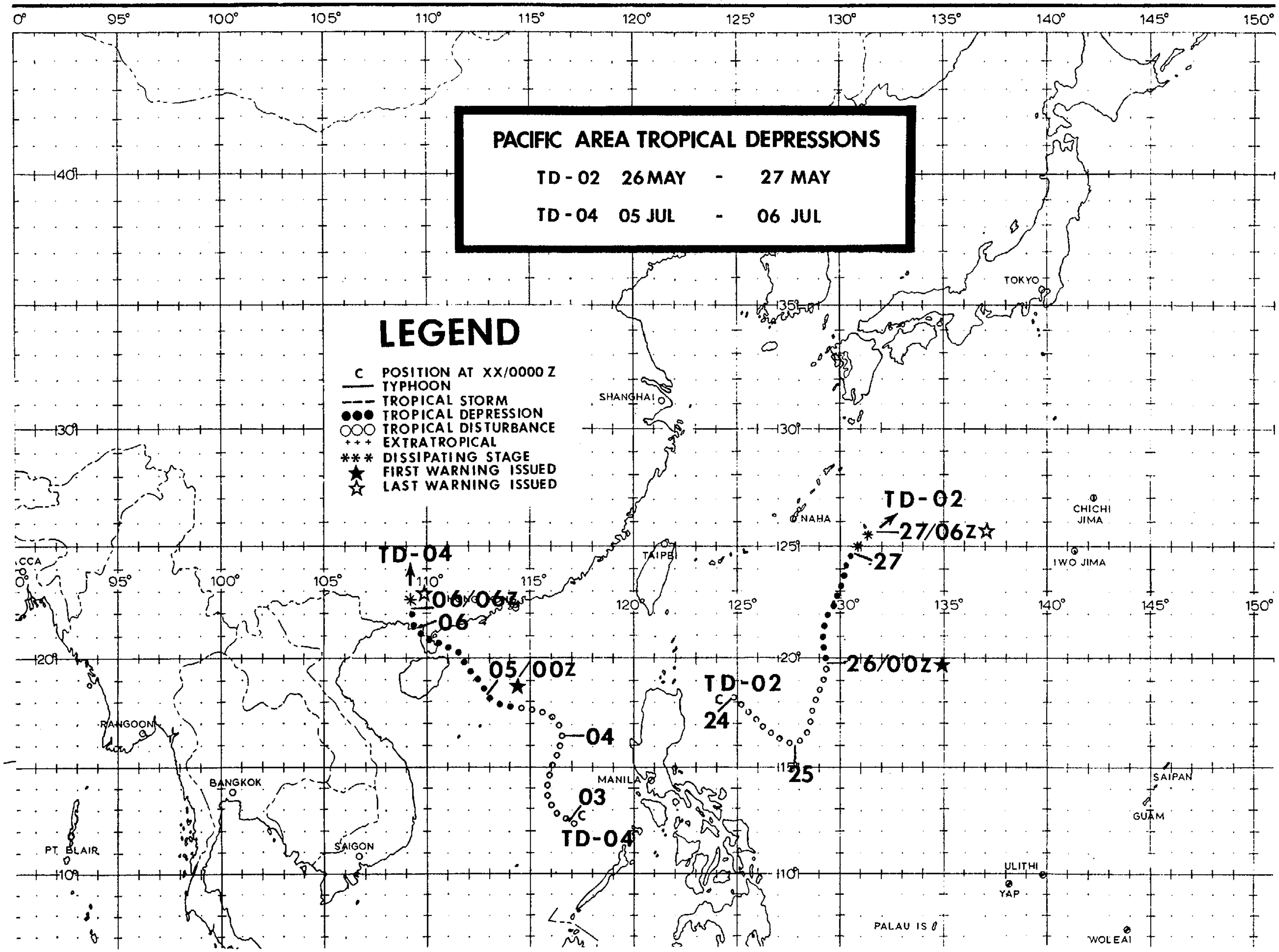
MONTHLY DISTRIBUTION

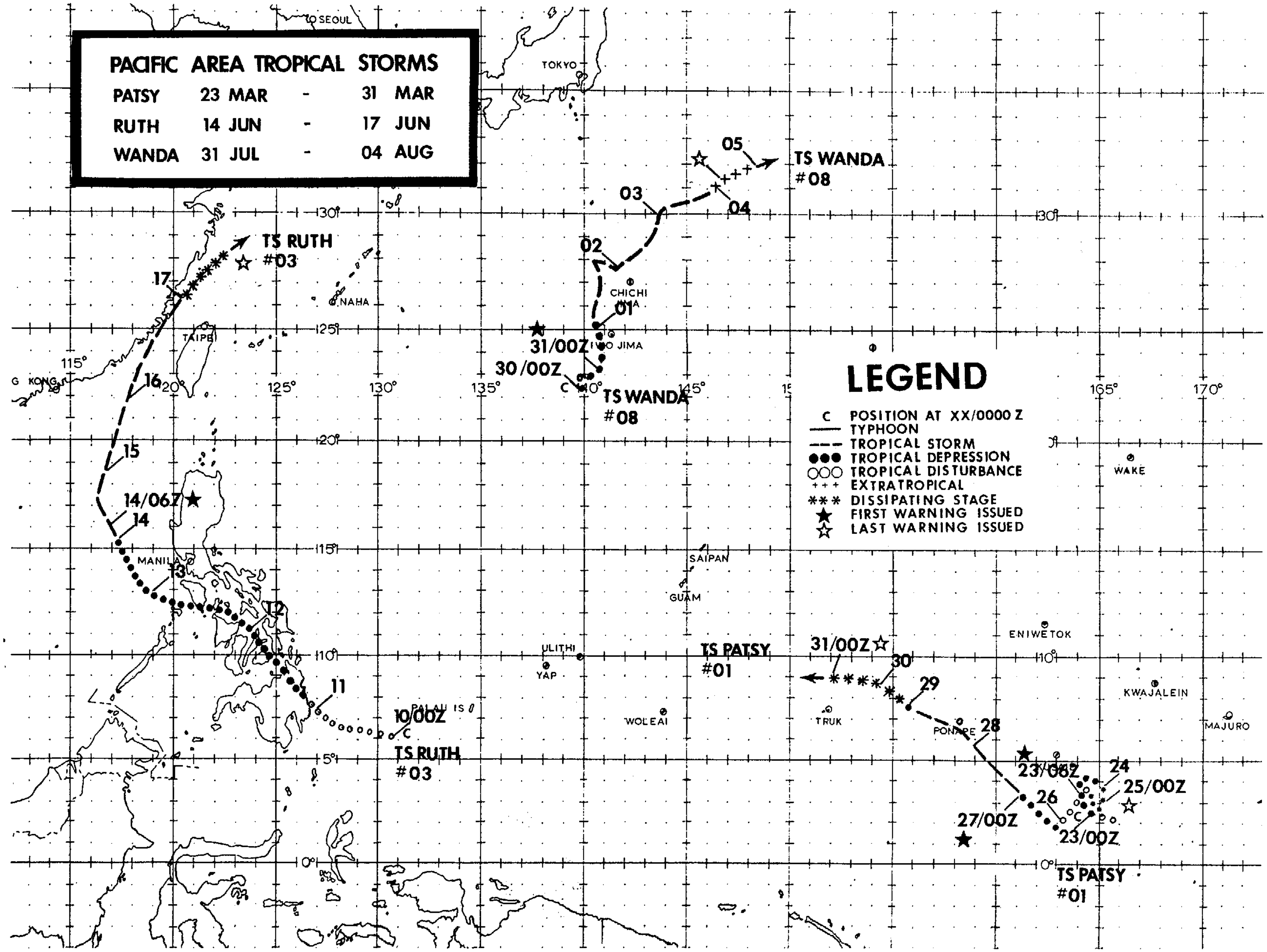
	J	F	M	A	M	J	J	A	S	O	N	D
FORMATION ALERTS	0	0	1	0	1	1	6	5	6	3	2	1

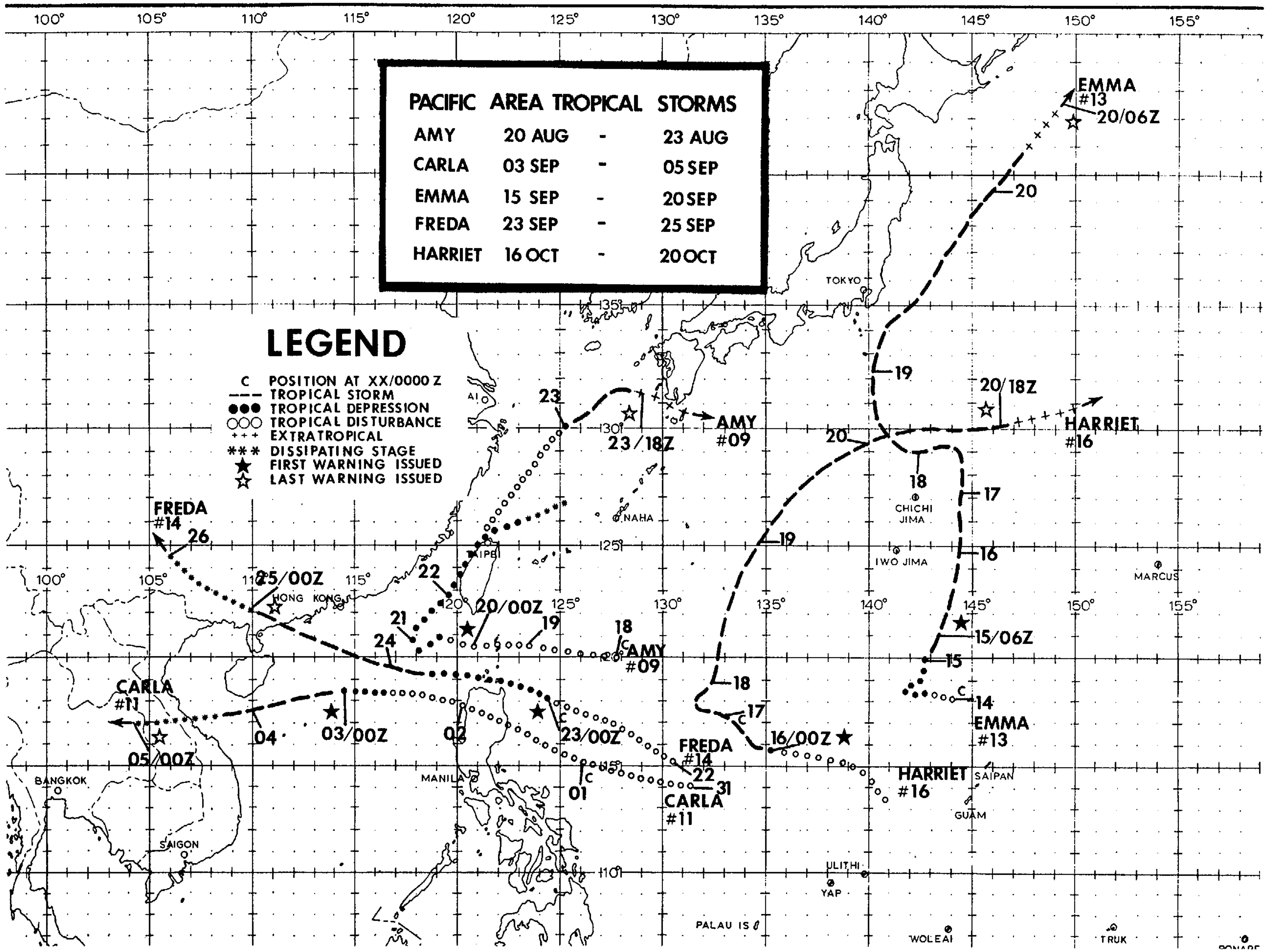
TABLE 4-5. SUMMARY OF JTWC WARNINGS 1959-1977.

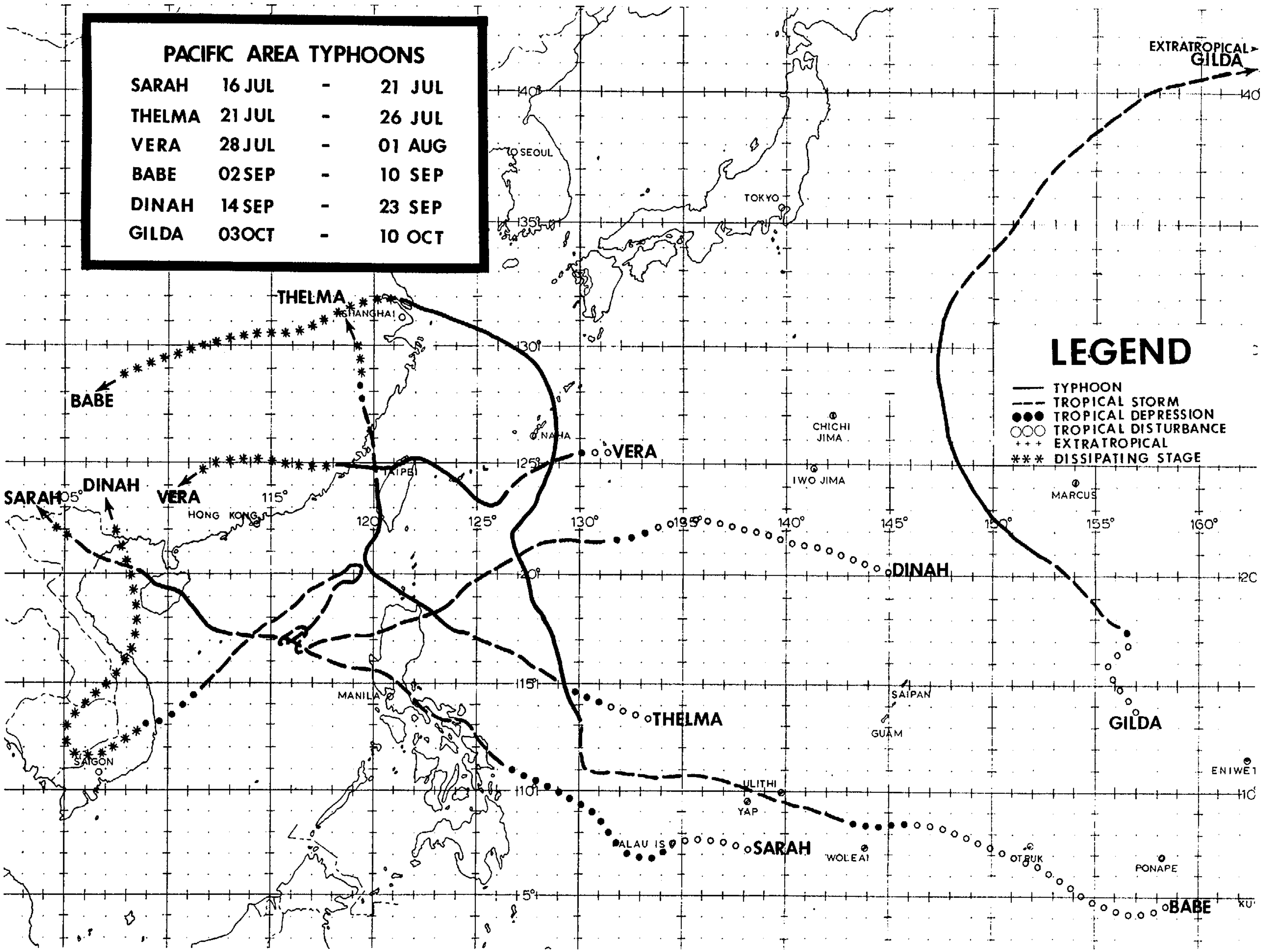
	WESTERN NORTH PACIFIC 1977	WESTERN NORTH PACIFIC AVERAGE 1959-76	NORTH INDIAN OCEAN 1977	NORTH INDIAN OCEAN AVERAGE 1971-76*	CENTRAL NORTH PACIFIC 1977	CENTRAL NORTH PACIFIC AVERAGE 1971-76
TOTAL NUMBER OF WARNINGS	492	679	44	26	0	35
CALENDAR DAYS OF WARNINGS	124	142	21	16	0	10
NUMBER OF WARNING DAYS WITH TWO CYCLONES	12	48	5	1	0	1
NUMBER OF WARNING DAYS WITH THREE OR MORE CYCLONES	0	9	0	0	0	0
TROPICAL DEPRESSIONS	2	5	-	-	0	1
TROPICAL STORMS	8	11	-	-	0	1
TYPHOONS/HURRICANES	11	19	-	-	0	1
I.O. TROPICAL CYCLONES	-	-	5	4	-	-
TOTAL TROPICAL CYCLONES	21	34	5	4	0	3

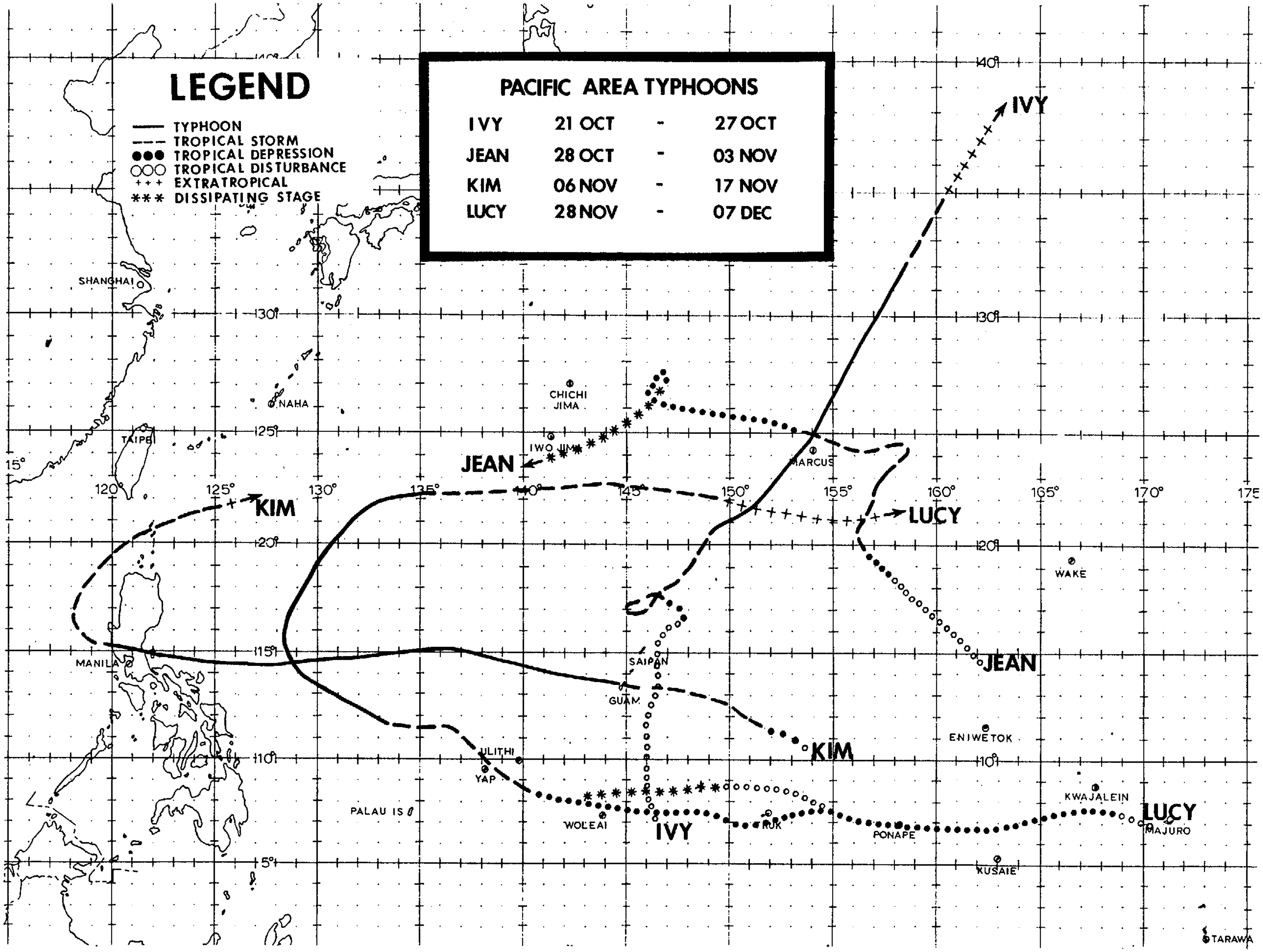
* 1971-1974 DOES NOT INCLUDE ARABIAN SEA


PACIFIC AREA TROPICAL DEPRESSIONS
TD - 02 26 MAY - 27 MAY
TD - 04 05 JUL - 06 JUL
LEGEND
C POSITION AT XX/0000 Z
TYPHOON
TROPICAL STORM
TROPICAL DEPRESSION
TROPICAL DISTURBANCE
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
TD-02
27/06Z
27
26/00Z
TD-02
24
25
TD-04
06/06Z
06
05/00Z
04
03
TD-04
TOKYO
SHANGHAI
NAHA
TAIPEI
CHICHI JIMA
IWO JIMA
MANILA
SAIPAN
GUAM
ULITHI
YAP
PALAU IS
WOLEAI
RANGOON
BANGKOK
SAIGON
PT. BLAIR


PACIFIC AREA TROPICAL STORMS
PATSY 23 MAR - 31 MAR
RUTH 14 JUN - 17 JUN
WANDA 31 JUL - 04 AUG
LEGEND
C POSITION AT XX/0000 Z
TYPHOON
TROPICAL STORM
TROPICAL DEPRESSION
TROPICAL DISTURBANCE
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
TS RUTH
#03
TS WANDA
#08
TS PATSY
#01
31/00Z
30/00Z
14/06Z
10/00Z
23/06Z
25/00Z
27/00Z
23/00Z
SEOUL
TOKYO
CHICHI JIMA
IWO JIMA
NAHA
TAIPEI
MANILA
SAIPAN
GUAM
ULITHI
YAP
WOLEAI
TRUK
PONAPE
ENIWETOK
WAKE
KWAJALEIN
MAJURO
PALAU IS


PACIFIC AREA TROPICAL STORMS
AMY 20 AUG - 23 AUG
CARLA 03 SEP - 05 SEP
EMMA 15 SEP - 20 SEP
FREDA 23 SEP - 25 SEP
HARRIET 16 OCT - 20 OCT
LEGEND
C POSITION AT XX/0000 Z
TROPICAL STORM
TROPICAL DEPRESSION
TROPICAL DISTURBANCE
+++ EXTRATROPICAL
*** DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
EMMA #13
20/06Z
20/18Z
HARRIET #16
AMY #09
23/18Z
FREDA #14
25/00Z
20/00Z
CARLA #11
05/00Z
03/00Z
23/00Z
16/00Z
15/06Z
TOKYO
NAHA
TAIPEI
HONG KONG
MANILA
BANGKOK
SAIGON
CHICHI JIMA
IWO JIMA
MARCUS
SAIPAN
GUAM
ULITHI
YAP
PALAU IS
WOLEAI
TRUK


PACIFIC AREA TYPHOONS
SARAH 16 JUL - 21 JUL
THELMA 21 JUL - 26 JUL
VERA 28 JUL - 01 AUG
BABE 02 SEP - 10 SEP
DINAH 14 SEP - 23 SEP
GILDA 03 OCT - 10 OCT
LEGEND
TYPHOON
TROPICAL STORM
TROPICAL DEPRESSION
TROPICAL DISTURBANCE
EXTRATROPICAL
DISSIPATING STAGE
EXTRATROPICAL
GILDA
THELMA
SHANGHAI
BABE
SEOUL
TOKYO
NAHA
VERA
CHICHI JIMA
IWO JIMA
MARCUS
SARAH
DINAH
VERA
HONG KONG
TAIPEI
DINAH
MANILA
THELMA
SAIPAN
GUAM
GILDA
SAIGON
ULITHI
YAP
ENIWETOK
PALAU IS
SARAH
WOLEAI
OTRUK
PONAPE
BABE


LEGEND
TYPHOON
TROPICAL STORM
TROPICAL DEPRESSION
TROPICAL DISTURBANCE
EXTRATROPICAL
DISSIPATING STAGE
PACIFIC AREA TYPHOONS
IVY 21 OCT - 27 OCT
JEAN 28 OCT - 03 NOV
KIM 06 NOV - 17 NOV
LUCY 28 NOV - 07 DEC
IVY
JEAN
KIM
LUCY
SHANGHAI
NAHA
TAIPEI
MANILA
CHICHI JIMA
IWO JIMA
MARCUS
SAIPAN
GUAM
ULITHI
YAP
PALAU IS
WOLEAI
TRUK
PONAPE
KUSAIE
WAKE
ENIWETOK
KWAJALEIN
MAJURO
TARAWA
40°
30°
25°
20°
15°
10°
5°
120°
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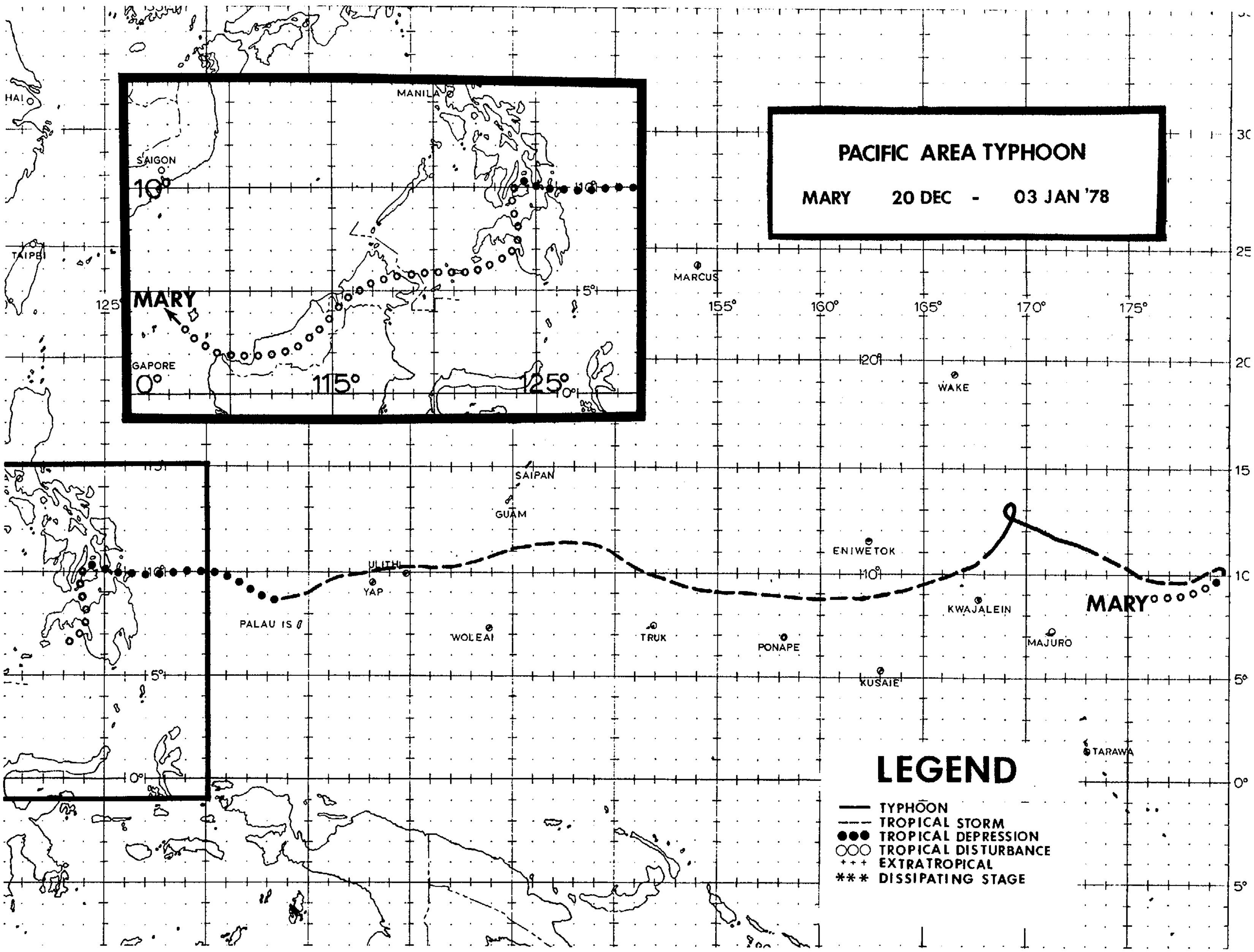
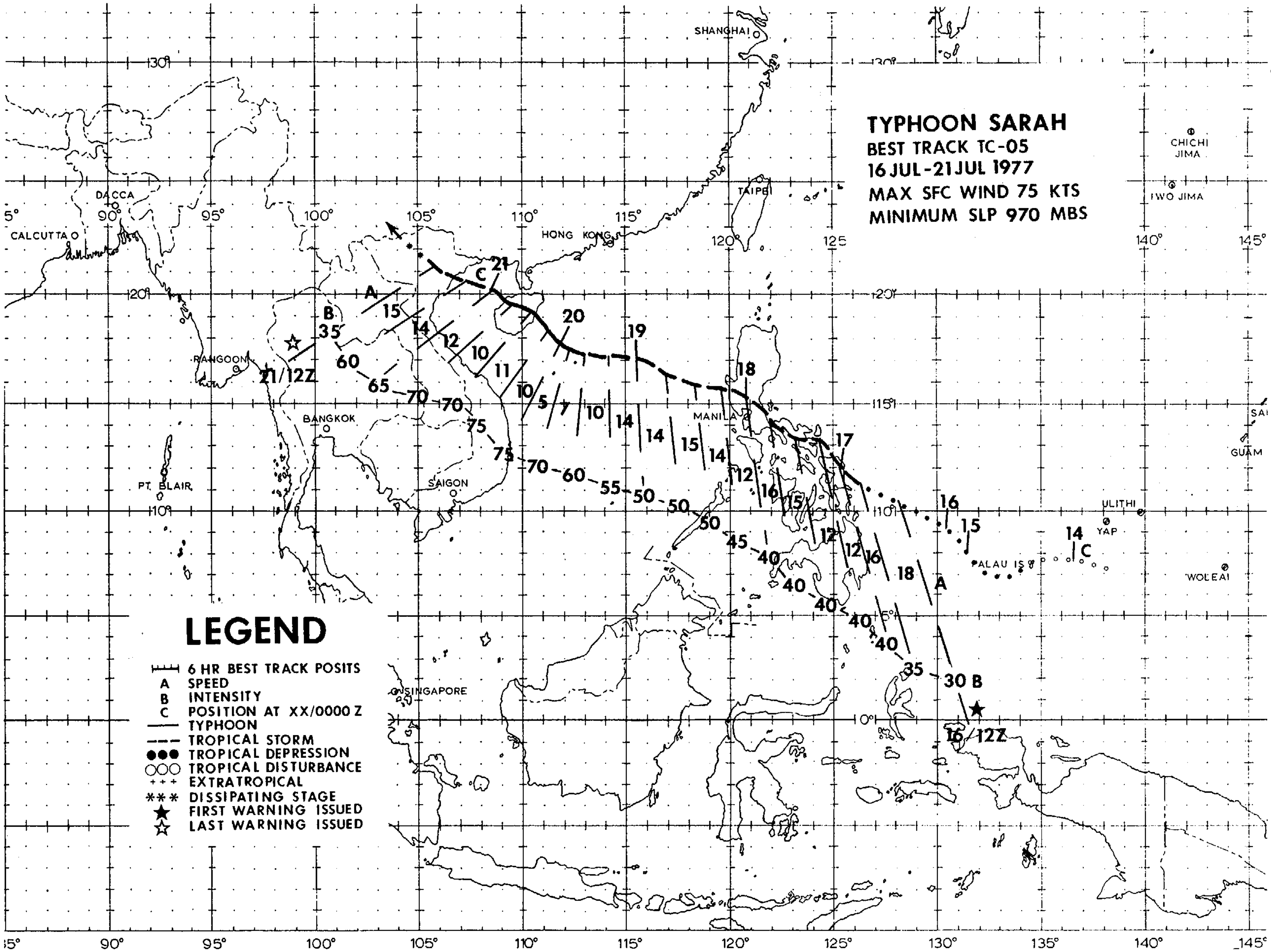
150°
155°
160°
165°
170°
175


PACIFIC AREA TYPHOON
MARY 20 DEC - 03 JAN '78
LEGEND
TYPHOON
TROPICAL STORM
TROPICAL DEPRESSION
TROPICAL DISTURBANCE
EXTRATROPICAL
DISSIPATING STAGE
MARY
MARY
MANILA
SAIGON
GAPORE
TAIPEI
MARCUS
WAKE
SAIPAN
GUAM
ULITHI
YAP
PALAU IS
WOLEAI
TRUK
PONAPE
KUSAIE
ENIWETOK
KWAJALEIN
MAJURO
TARAWA
155°
160°
165°
170°
175°
115°
125°


TYPHOON SARAH
BEST TRACK TC-05
16 JUL-21 JUL 1977
MAX SFC WIND 75 KTS
MINIMUM SLP 970 MBS
LEGEND
6 HR BEST TRACK POSITS
A SPEED
B INTENSITY
C POSITION AT XX/0000 Z
TYPHOON
TROPICAL STORM
TROPICAL DEPRESSION
TROPICAL DISTURBANCE
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
SHANGHAI
TAIPEI
HONG KONG
MANILA
DACCA
CALCUTTA
RANGOON
BANGKOK
SAIGON
PT. BLAIR
SINGAPORE
CHICHI JIMA
IWO JIMA
GUAM
ULITHI
YAP
PALAU IS
WOLEAI
21/12Z
16/12Z
90°
95°
100°
105°
110°
115°
120°
125°
130°
135°
140°
145°

The first typhoon of the 1977 season did not occur until mid-July. Meteorological satellite data on the morning of July 13th showed an area of convection some 225 nm (417 km) east of Koror (WMO 91408) in the Palau Islands. This tropical disturbance meandered on a 10 kt (19 km/hr), westward track and crossed Koror at 1200Z on the 14th. On the morning of the 15th, the system exhibited increased organization and a Tropical Cyclone Formation Alert was issued at 0000Z. Simultaneously, the disturbance took a more climatological, west-northwestward track and showed evidence of possessing multiple circulation centers.

During the 16th, satellite data hinted that the western-most circulation center was becoming the dominant one. Reconnaissance aircraft refuted this however, and fixed the primary center approximately 200 nm (370 km) east of the satellite positions. At 0943Z aircraft observed 38 kt (20 m/sec) winds at 700 mb and estimated surface winds at 25 kt (13 m/sec). Satellite data an hour later showed that convection in the area had, in fact, consolidated around the aircraft-fixed circulation center, and the first warning on Tropical Depression (TD) number 05 was issued at 1200Z.

By the evening of the 16th, TD 05 had accelerated to 17 kt (31 km/hr), and satellite data illustrated increased organization. At 1800Z the depression was upgraded to Tropical Storm Sarah, while located 30 nm (56 km) east of the Philippine island of Samar. During the subsequent 24 hours, Sarah, possessing 40 kt (21 m/sec) intensity, moved toward Manila at 13 kt (24 km/hr) on a west-northwest to northwest heading (Fig. 4-1). At 2355Z on the 17th, Clark AB observed a minimum sea level pressure of 997.3 mb; winds were from the northwest at 12 kt (6 m/sec). Within two hours winds at the Air Base had become southerly. Synoptic reports were of great value during this period. The mountainous terrain prevented aircraft reconnaissance of the low level circulation center, while frictional effects weakened and disorganized Sarah making satellite positioning very difficult.

From the evening of the 16th until the morning of the 20th upper level patterns in Sarah's environment were favorable for enhancement of her upper level outflow, which would normally result in intensification. The Tropical Upper Tropospheric Trough (TUTT) was oriented east-west, north of her and was enhancing outflow in the north semicircle; strongly divergent winds south of the tropical storm increased outflow to the south. While over land, however, Sarah could not intensify since the latent and sensible heat required to maintain sufficient thermal and related pressure gradients were not available. The tropical storm entered the South China Sea on the afternoon of the 18th and immediately began to intensify.

On the evening of the 19th, a mid-tropospheric low over south central China deepened and weakened the subtropical ridge north of Sarah; she responded and turned to the northwest; toward Hainan Island, still intensifying. Sarah was upgraded to a typhoon at 1800Z and six hours later reached its maximum intensity of 75 kt (39 m/sec). At 2100Z Hsi-Sha-Tao (WMO 59981) reported sustained winds (10 minute average) of 60 kt (31 m/sec) from the west-southwest and a sea level pressure of 977.5 mb.

Sarah went ashore on Hainan Island on the evening of the 20th. At 1200Z Ch'iung-Hai (19.3N-110.5E) reported 10 kt (5 m/sec) winds from the west and a sea level pressure of 978.5 mb. At this time Sarah's intensity was estimated to be 70 kt (36 m/sec). Meanwhile, the mid-level low over China had receded toward the north and the subtropical ridge began to build westward, north of Sarah. During the subsequent six hours, the typhoon slowed to 8 kt (15 km/hr) and took a westward course, passing north of the central mountain range of Hainan. At 1800Z Tan-Hsien (19.5N-109.6E) was near the center when it reported 15 kt (8 m/sec) winds from the east-northeast and a sea level pressure of 969.5 mb.

Typhoon Sarah entered the Gulf of Tonkin on the morning of the 21st with an estimated 65 kt (33 m/sec) intensity. The typhoon accelerated to 15 kt (28 km/hr) and went ashore near Haiphong. At 0600Z on the 21st, Kien-an Phulien (20.8N-106.6E), a Haiphong suburb, reported north-northwesterly winds of 30 kt (15 m/sec) and a sea level pressure of 986.9 mb. Six hours later these values had changed to 30 kt (15 m/sec) from the south and 988.5 mb with pressure rising rapidly.

The final warning on Sarah was issued at 1200Z on the 21st as she was dissipating over the Red River Valley, northwest of Hanoi. Very little damage occurred during Sarah's existence. Only Hanoi Radio reported cases of destruction with no casualties.

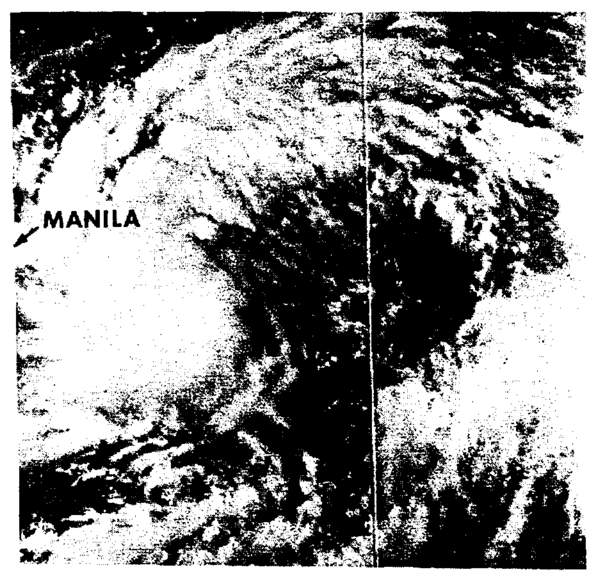
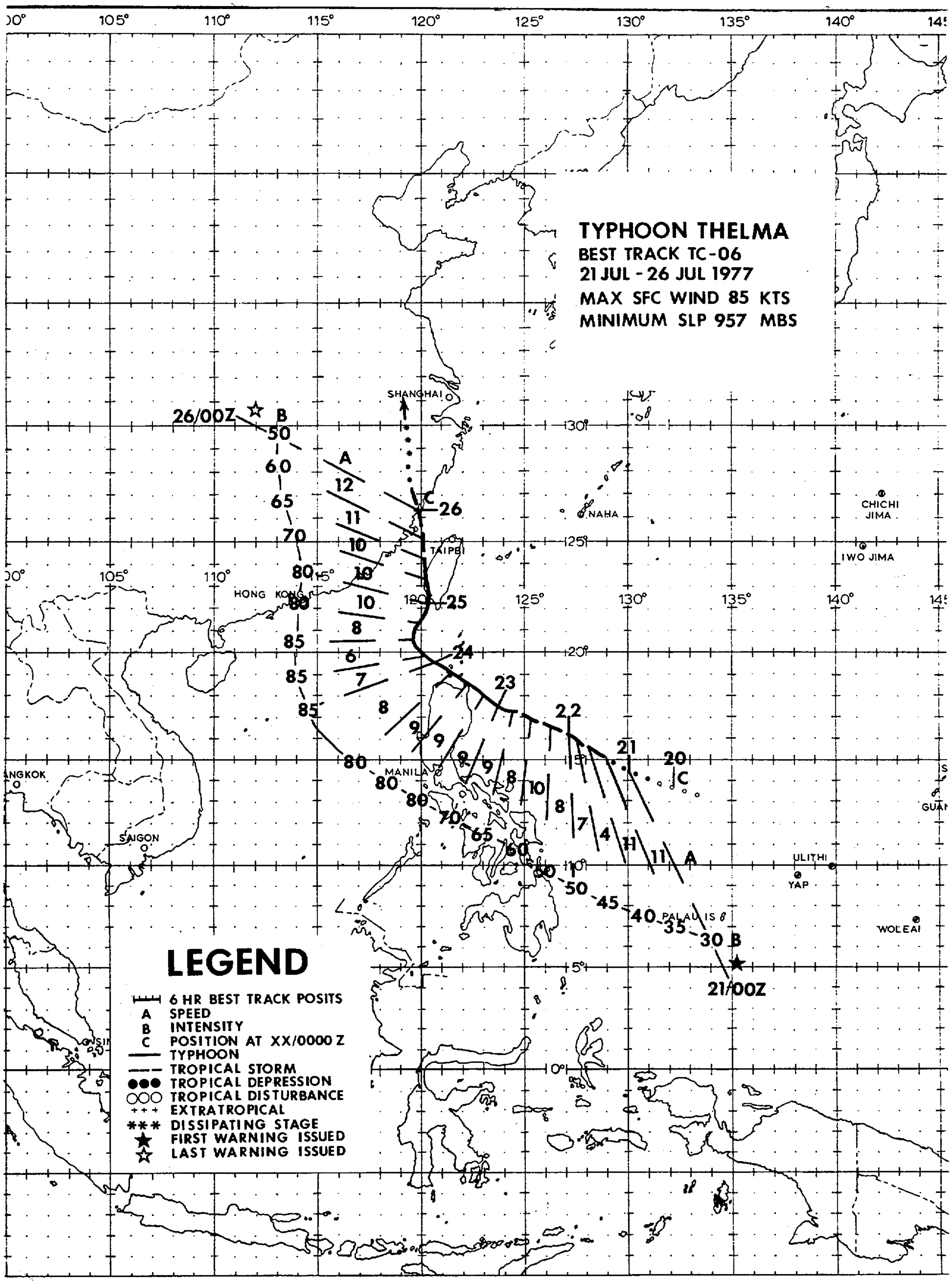


FIGURE 4-1. Sarah at 40 kt (21 m/sec) intensity crossing northeastern Samar, RP, 17 July 1977, 0057Z. (NOAA-5 imagery)


TYPHOON THELMA
BEST TRACK TC-06
21 JUL - 26 JUL 1977
MAX SFC WIND 85 KTS
MINIMUM SLP 957 MBS
LEGEND
6 HR BEST TRACK POSITS
A SPEED
B INTENSITY
C POSITION AT XX/0000 Z
TYPHOON
TROPICAL STORM
TROPICAL DEPRESSION
TROPICAL DISTURBANCE
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
26/00Z
21/00Z
SHANGHAI
TAIPEI
HONG KONG
MANILA
SAIGON
NAHA
CHICHI JIMA
IWO JIMA
ULITHI
YAP
PALAU IS
WOLEAI
GUAM
BANGKOK
105°
110°
115°
120°
125°
130°
135°
140°

Thelma, the second typhoon of the 1977 season, wrought more destruction on Taiwan than any event since World War II. While Typhoon Sarah was still crossing the South China Sea, Thelma was detected by satellite on the morning of July 20th as a tropical disturbance in the central Philippine Sea. The disturbance continued to organize during the subsequent 24 hours, and the first warning was issued on TD 06 at 0000Z on the 21st.

Reconnaissance aircraft at 0918Z on the 21st found flight level winds of 55 kt (28 m/sec), a central pressure of 993 mb, and surface winds estimated at 50 kt (26 m/sec). Based on the aircraft data and corroborating satellite data, TD 06 was upgraded to Tropical Storm Thelma at 1200Z. During the following 30 hours, Thelma continued to intensify at a rate of 5 kt (2.6 m/sec) per 6 hours. At 2050Z on the 22nd, aircraft fixed the tropical storm 255 nm (472 km) northeast of Manila, and observed 60 kt (31 m/sec) winds at its 700 mb flight level. The aircraft further indicated that the central pressure had fallen to 965 mb. As a result of those observations, the system was upgraded to Typhoon Thelma at 0000Z on the 23rd.

The trigger for Thelma's intensification was nearly identical to that of Sarah's a week earlier. Highly efficient outflow channels were provided Thelma by intense cyclonic cells in the TUTT, to the north, and by strongly divergent upper level northeasterlies over Indonesia and the South China Sea, to the south. This situation lasted from the 21st to the 24th when the TUTT receded northward, and Thelma ceased her intensification.

The typhoon continued to move northwestward at 9 kt (17 km/hr) toward the southern periphery of the mid-tropospheric subtropical ridge. On the evening of the 23rd, the storm entered the Bashi Channel, passing 10 nm (19 km) northeast of Escarpada Point on northeastern Luzon. At this time the Kakuho Maru reported 80 kt (41 m/sec) winds and 20 ft (6 m) seas just northwest of the center.

Since the time of Thelma's development, the mid-tropospheric subtropical ridge had been intense over the western Pacific and extended well into China. By 1200Z on the 23rd, geopotential heights at the 500 mb level began to fall over northern China as a low developed over eastern Monogolia and deepened rapidly. On the morning of the 24th, the subtropical ridge north of the tropical system showed signs of weakening.

During the evening of the 24th, reconnaissance aircraft positioned Thelma 145 nm (269 km) south-southwest of Kao-hsiung, which indicated that the storm was beginning to move northward. At this time the typhoon attained its maximum intensity of 85 kt (44 m/sec) with a minimum pressure of 957 mb, and slowed to 6 kt (11 km/hr). At 1800Z the passenger liner, President McKinley, reported 45 kt (23 m/sec) winds and 20 ft (6 m) seas while some 70 nm (130 km) northeast of the eye.

On the morning of the 25th, radar data showed that Thelma had turned toward the north-northeast and had accelerated to 10 kt (19 km/hr). When satellite confirmed the radar movement, the 241800Z warning was amended to reflect the system's impending threat to southern Taiwan. During early afternoon of the 25th, Thelma crashed into Kao-hsiung harbor (Fig. 4-2). The Chinese Weather Central reported that Kao-hsiung (WMO 46744) observed 86 kt (44 m/sec) peak winds accompanied by a 991.5 mb pressure minimum at 250939 local. Satellite, aircraft, radar, and synoptic data all indicated that the typhoon was small, but very intense. Most damage was confined to the direct path of Typhoon Thelma as the central mountain range of Taiwan drastically weakened the peripheral winds east of the typhoon's track.

After moving across southwestern-Taiwan, Thelma began to weaken, and move on a track slightly west of north. On the evening of the 25th, Thelma entered the Taiwan Straits, and on the following morning went ashore on mainland China, 30 nm (56 km) north of Fu-Chou with 50 kt (26 m/sec) winds.

During her rampage over Taiwan, Thelma claimed more than 30 lives, injured thousands, and rendered an estimated 5,000 homeless. The typhoon ripped down 53 steel towers supporting high-tension power lines. The loss of power shut down more than one-half of the island's 45,000 factories. Taiwan's largest harbor at Kao-hsiung was virtually destroyed. All eight giant cranes used to load and unload cargo were badly damaged or destroyed. At least 17 ships capsized in the harbor. In her few short hours over southern Taiwan, Thelma left destruction amounting to several millions of dollars (U.S.). According to the Central Weather Bureau of Taiwan, Typhoon Thelma was the most destructive tropical cyclone to hit Taiwan in more than 80 years.

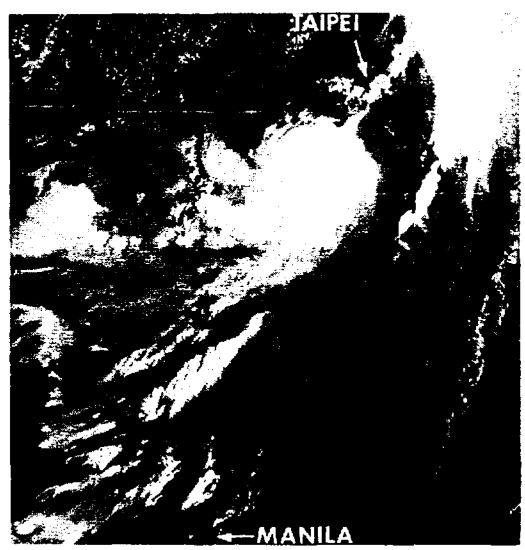
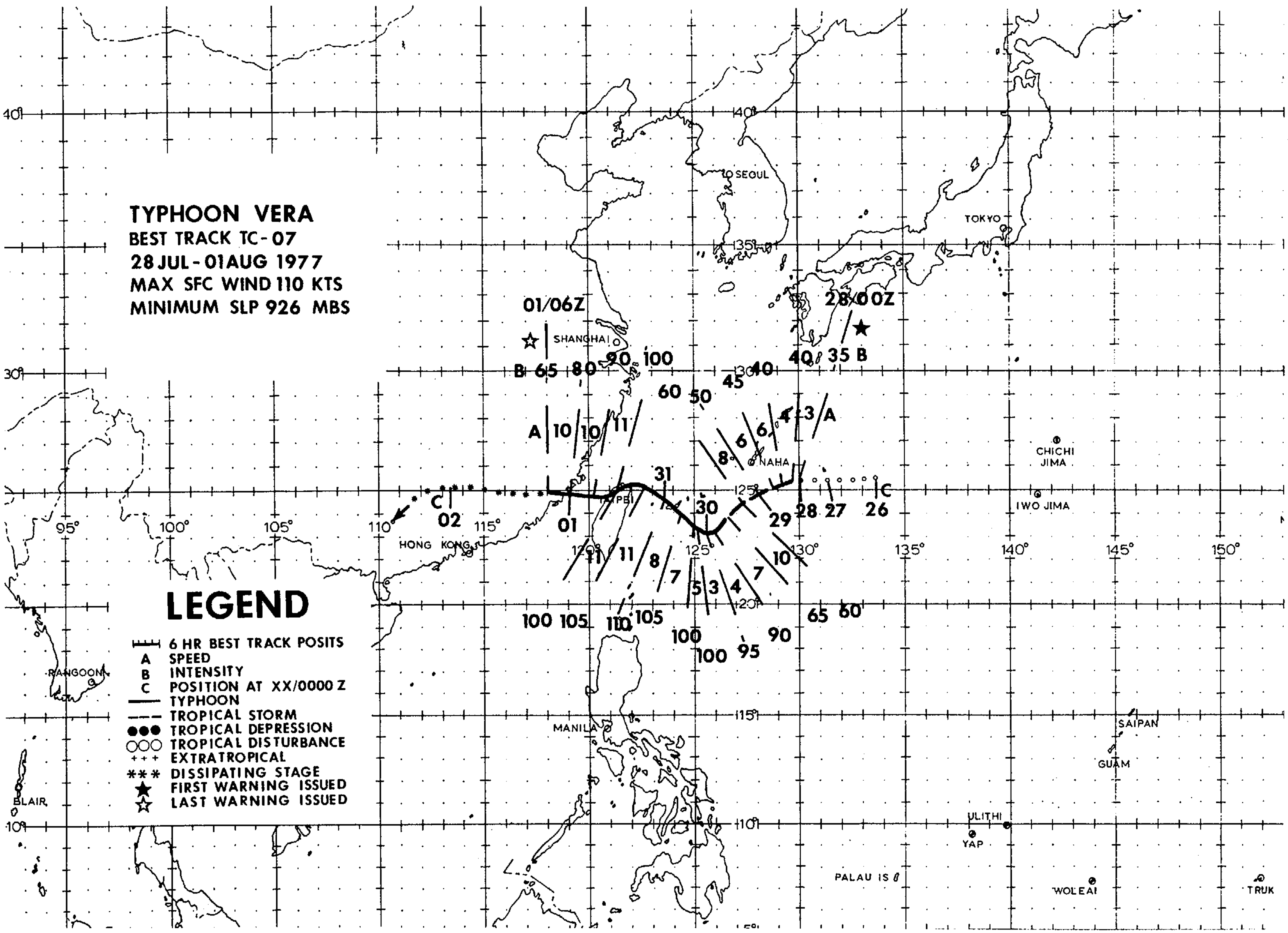


FIGURE 4-2. Typhoon Thelma entering southwestern Taiwan with an 80 kt (41 m/sec) intensity, 25 July 1977, 0243Z. (DMSP imagery)


TYPHOON VERA
BEST TRACK TC-07
28 JUL-01AUG 1977
MAX SFC WIND 110 KTS
MINIMUM SLP 926 MBS
LEGEND
6 HR BEST TRACK POSITS
A SPEED
B INTENSITY
C POSITION AT XX/0000 Z
TYPHOON
TROPICAL STORM
TROPICAL DEPRESSION
TROPICAL DISTURBANCE
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
01/06Z
28/00Z
SHANGHAI
SEOUL
TOKYO
NAHA
TAIPEI
HONG KONG
MANILA
RANGOON
BLAIR
CHICHI JIMA
IWO JIMA
SAIPAN
GUAM
ULITHI
YAP
PALAU IS
WOLEAI
TRUK
95°
100°
105°
110°
115°
120°
125°
130°
135°
140°
145°
150°

A tropical disturbance, north of the climatologically favored area, was first evident on satellite imagery and JTWC's synoptic gradient level analysis at 260000Z July 77 with a cyclonic surface circulation center near 25.5N-133.6E. Exhibiting westward movement over the next 24 hour period, the disturbance gained organization and potential for significant development. At 270500Z, a formation alert was issued. By 271800Z the surface circulation reflected 30 kt (15 m/sec) of wind at the surface and JTWC's initial warning on the system as Tropical Depression 07 (TD 07) was issued at 280000Z. Subsequent post-storm analysis revealed that TD 07 had reached 35 kt (18 m/sec) intensity (minimum tropical storm intensity) by initial warning time.

Beginning as far back as 220000Z, a low cell imbedded in a tropical upper tropospheric trough (TUTT) had formed to the northeast of TD 07's initial warning position. Tracking west-southwest, this upper cell was centered near 30.5N-131.0E at 260000Z. The TUTT, now nearly east-west oriented, continued to dig toward the west and at the same time an upper level anticyclone over Korea/Japan north of this TUTT built eastward. The 200 mb winds at stations along the east coast of Japan reflected 60-75 kt (31-39 m/sec) out of the north-northeast. By 271200Z the TUTT cell was centered near 27.8N 133.5E with strong difluence southeast of the cell located over the surface disturbance (Fig. 4-3). The vertical coupling had thus been effected and the necessary conditions for tropical cyclone development fulfilled.

By 280000Z, then, TD 07 was upgraded to a tropical storm and named Vera. A generally westward track (260°) at 3 kt (5.6 km/hr) was observed. Steering at this point seemed to be governed by the easterly flow on the southern periphery of the major anticyclone over Korea/Japan. The TUTT low also moved westward. By 291200Z the anticyclone over Korea/Japan began to build toward the southwest in advance of Vera. Therefore, steering influences were reflected in the observed west-southwest (becoming southwest) track that Vera assumed. As she proceeded southwestward, Vera continued to intensify attaining 65 kt (34 m/sec) by 291200Z. From 291200Z to 291800Z Vera intensified from 65 to 90 kt (34 to 46 m/sec) proceeding to the southwest at 9 kt (17 km/hr). Beyond 291800Z a marked decrease in forward speed was noted (from 9 to 4 kt [17 to 7.4 km/hr]) as the northeasterly steering at upper levels appeared to relax. Simultaneously, an increase in intensity occurred. By 300600Z Vera had attained winds of 100 kt (52 m/sec) and satellite imagery revealed a well-defined eye (Fig. 4-4) while reconnaissance aircraft reported 100 kt (52 m/sec) at the 700 mb flight level. By 301200Z satellite data showed improved outflow channels aloft to the west and north and fix positions from radar, satellite, and aircraft supported a more west-northwestward track.

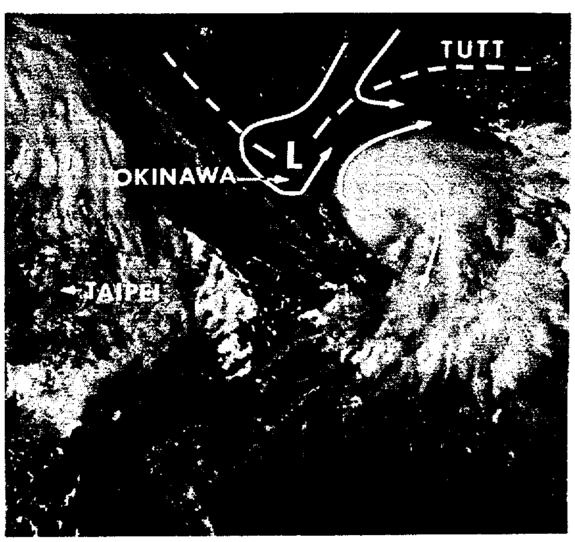


FIGURE 4-3. *Vera at barely 40 kt (21 m/sec) intensity showing strong difluence aloft to the southeast of a TUTT low, 28 July 1977, 0039Z. (NOAA-5 imagery)*

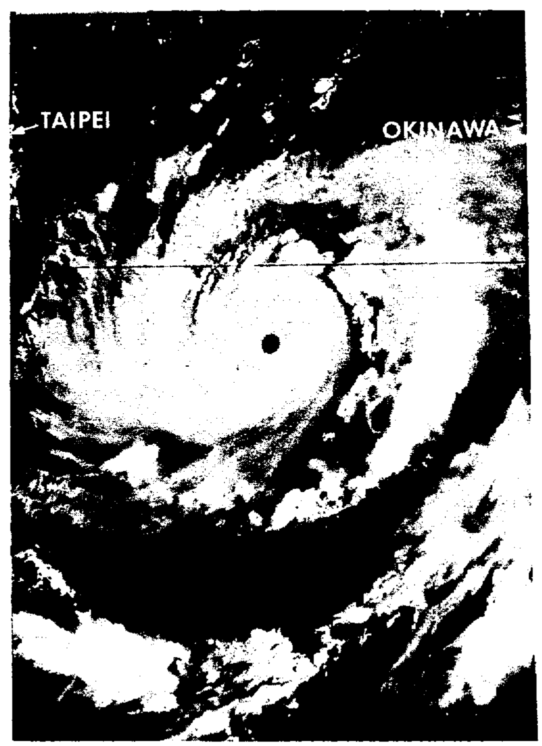


FIGURE 4-4. *Typhoon Vera 200 nm (370 km) east of Taiwan and accelerating northwestward.*

Upon making her turn to the west-northwest, it became evident that Vera would likely pass directly over Iriomote-Jima and just to the south of Ishigaki-Jima. Figure 4-5 shows the one-hourly surface reports from Ishigaki-Jima (WMO 47978) and indicates eye passage south of the island between 302100Z and 302200Z. Maximum winds reported were from the southeast at 103 kt (53 m/sec) at 302200Z (Fig. 4-6). Minimum pressure reported was 935.6 mb at 302100Z. As Vera passed south of Ishigaki-Jima, her speed had increased to 10 kt (19 km/hr). Post-analysis revealed that Vera attained her maximum intensity of 110 kt (57 m/sec) by 310000Z (Fig. 4-7) and decreased in intensity slowly thereafter as she approached Taiwan at a speed of 11 kt (20 km/hr) (Fig. 4-8). Aircraft reconnaissance at 310850Z verified a slight intensity decrease as low level inflow channels were restricted by the island of Taiwan.

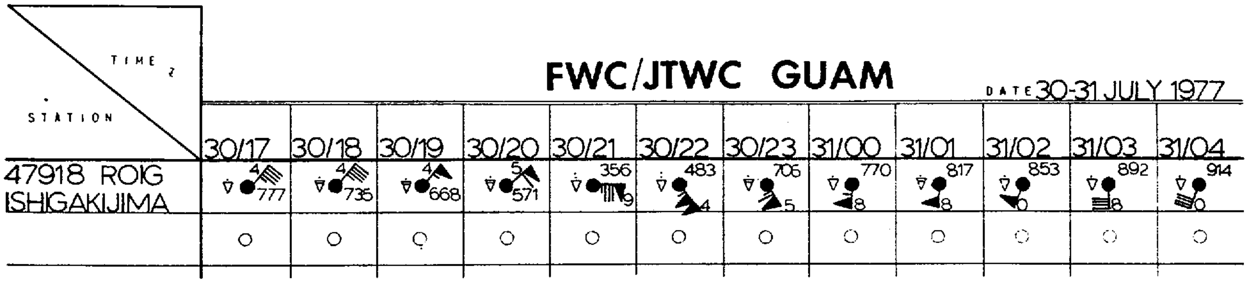


FIGURE 4-5. *Hourly surface synoptic observations from Ishigaki-Jima during passage of Typhoon Vera.*

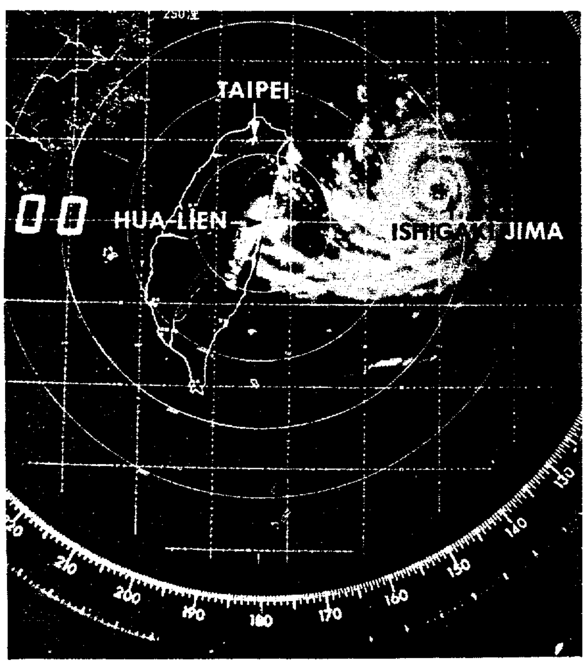


FIGURE 4-6. *Hua-Lien radar presentation of Typhoon Vera when Ishigaki-Jima was receiving maximum sustained winds of 103 kt (53 m/sec), 30 July 1977, 2200Z. (Photograph courtesy of the Central Weather Bureau, Taipei, Taiwan, Republic of China.)*

FIGURE 4-7. *Typhoon Vera at maximum 110 kt (57 m/sec) intensity and just 19 minutes after the radar imagery in Figure 4-6, 30 July 1977, 2219Z. (DMSP imagery)*

Landfall on the island of Taiwan occurred at Keelung (Chi-Lung) at the mouth of the Chi-Lung Ho River basin. Moving at 11 kt (20 km/hr) Vera followed the river basin to the west-southwest toward Taipei. Keelung recorded a minimum low pressure of 939.9 mb at 310930Z and a total rainfall of 7.95 in (202 mm). Maximum winds recorded at the Chinese Weather Bureau office in downtown Keelung were 66.6 kt (34 m/sec) with gusts to 113 kt (58 m/sec) at 311030Z. In Taipei, a minimum pressure of 951.5 mb was recorded at 311028Z with total rainfall recorded as 8.0 in (203 mm). Taipei International Airport reported maximum winds of 64 kt (33 m/sec) with gusts to 96 kt (49 m/sec). Both Keelung and Taipei established new records in observed maximum wind reports with Vera's passage. After passing over the northeastern part of Taipei city, Vera continued on a nearly westward track and emerged in the Taiwan Straits just north of Hsin Chu at 311500Z. Vera continued on a westward track at 11 kt (20 km/hr) and made landfall on the China mainland near Ch'uan-Chou at 010100Z August with an intensity of 80 kt (41 m/sec).

Following so closely after Typhoon Thelma, which had wreaked havoc on the southern portion of Taiwan, Typhoon Vera left at least 25 dead in her wake and vast amounts of property and crop damage. Two ships sank, 10 went aground, 3 were washed away, and 22 were damaged. However, with timely warnings and the occurrence of Thelma two weeks prior, most ships diverted and rode out the storm in the safety of the open sea.

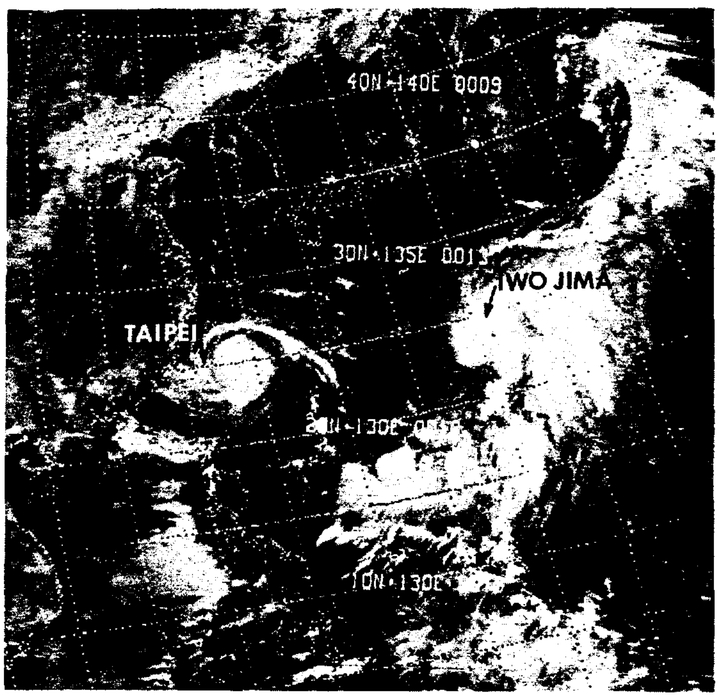
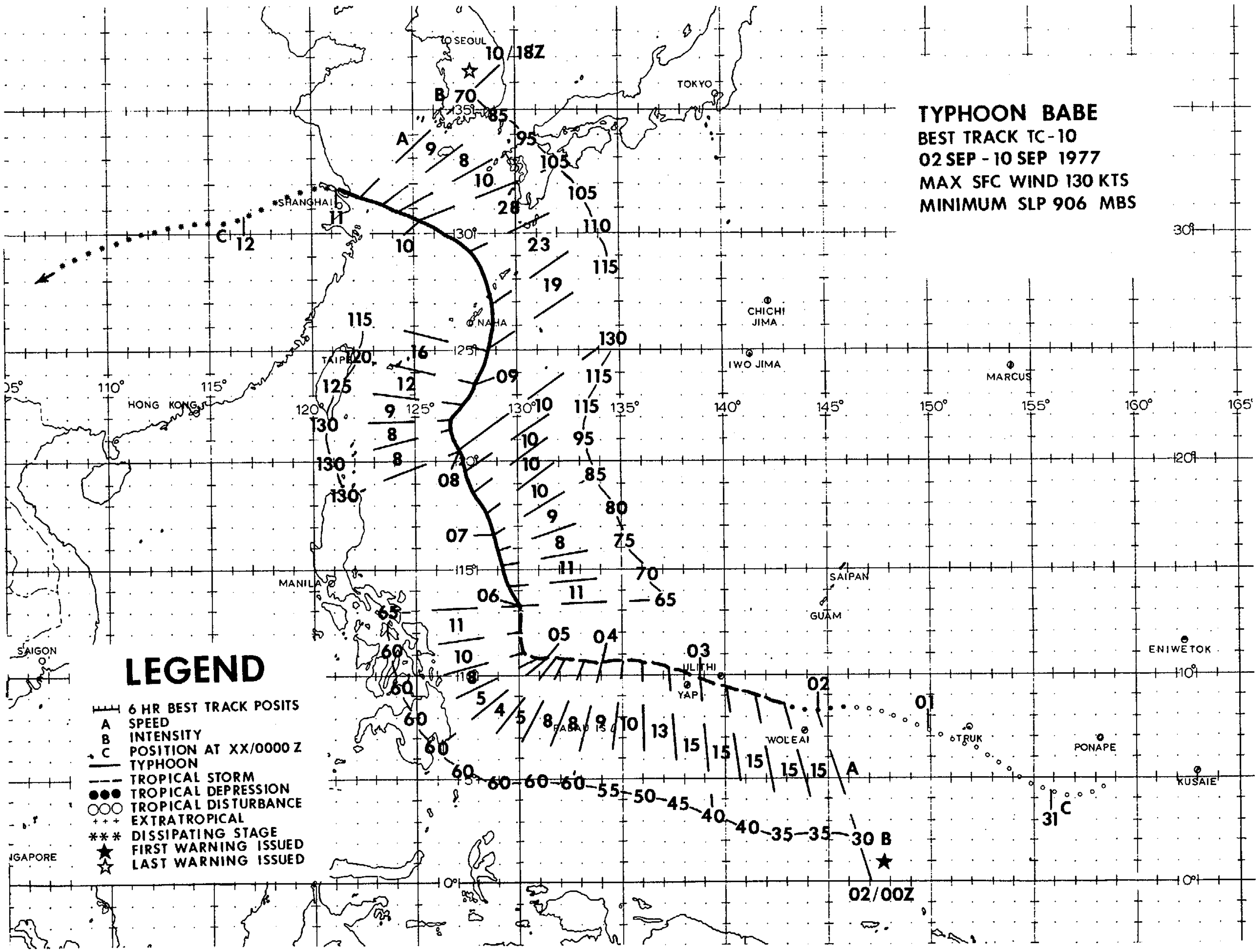


FIGURE 4-8. Typhoon Vera approaching northern Taiwan, 30 July 1977, 2352Z. The next cyclone, Tropical Storm Wanda, is shown at development stage with 30 kt (15 m/sec) winds 100 nm (185 km) south of Iwo-Jima. (NOAA-5 imagery from FLEWEAFAC Suitland, MD)


TYPHOON BABE
BEST TRACK TC-10
02 SEP - 10 SEP 1977
MAX SFC WIND 130 KTS
MINIMUM SLP 906 MBS
LEGEND
6 HR BEST TRACK POSITS
A SPEED
B INTENSITY
C POSITION AT XX/0000 Z
TYPHOON
TROPICAL STORM
TROPICAL DEPRESSION
TROPICAL DISTURBANCE
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
10/18Z
02/00Z
SEOUL
TOKYO
SHANGHAI
NAHA
TAIPEI
HONG KONG
MANILA
SAIGON
CHICHI JIMA
IWO JIMA
MARCUS
SAIPAN
GUAM
ULITHI
YAP
WOLEAI
TRUK
PONAPE
ENIWETOK
KUSAIE

During August 1977, no typhoons were observed. The JTWC significant Tropical Weather Advisory of 31 August stated, "the probability is that the remainder of 1977 should see an increase in typhoon activity". The next day, 1 September, the seedling of the year's 10th tropical cyclone and the only super typhoon was first observed. Babe was a very challenging storm in that during her lifetime she threatened virtually every major DoD facility in the western North Pacific.

Satellite data on the 1st at 0143Z and 0000Z synoptic data indicated a weak surface circulation with associated convection near 7N-150E. Based on this data, a Tropical Cyclone Formation Alert was issued. At this time, there was a tropical upper tropospheric trough (TUTT) present at 200 mb to the North of the alert area. The TUTT maintained its position through the 3rd at 0000Z and the divergence on the southern side of the TUTT aided in the development of the seedling into Tropical Depression 10 (TD 10).

The first warning on TD 10 was issued on the 2nd at 0000Z. An aircraft fix on the 2nd at 0052Z estimated the maximum surface wind to be 40 kt (21 m/sec). On the following warning (0600Z), TD 10 was upgraded to Tropical Storm Babe. With the TUTT circulation providing fair outflow conditions aloft, Babe slowly intensified as she moved westward across the warm Philippine Sea. Babe was being steered at this time by a well developed mid-tropospheric subtropical ridge which extended from the dateline into central China. With this westward movement expected to continue, Babe was forecast to cross the Republic of the Philippines and pose a threat to Subic Bay and Clark AB. The westward movement continued until the 5th at 0000Z when signs of a change in direction of movement first appeared. Between the 2nd and the 4th, Babe had an average speed of 14 kt (25 km/hr). By the 4th at 1200Z, the speed had dropped to 8 kt (14 km/hr), further dropping to 5 kt (9 km/hr) in the following 12 hours.

On the 5th at 0000Z, an upper air trough in the mid-latitude westerlies appeared over northeastern Asia. A weakness in the subtropical ridge between the trough and Babe became evident and increased the probability of a more northerly storm track. A change in Babe's direction of movement was first noted by satellite data at 052155Z (Fig. 4-9) and confirmed by aircraft reconnaissance at 052243Z.

Taiwan, which was still recovering from the effects of earlier typhoons, Thelma and Vera, was now threatened again. Aircraft data between the 5th at 0832Z and the 7th at 2204Z showed Babe to have undergone rapid deepening with the central pressure dropping from 988 mb to 907 mb, a rate of 1.3 mb/hr. This rapid deepening was in response to the divergent southwesterly flow ahead of the strong upper air trough now stretching from east of Japan into central Taiwan, which provided a strong outflow channel aloft. Babe was upgraded to a typhoon on the 6th at 0000Z and a super typhoon on the 8th at 0000Z (Fig. 4-10).

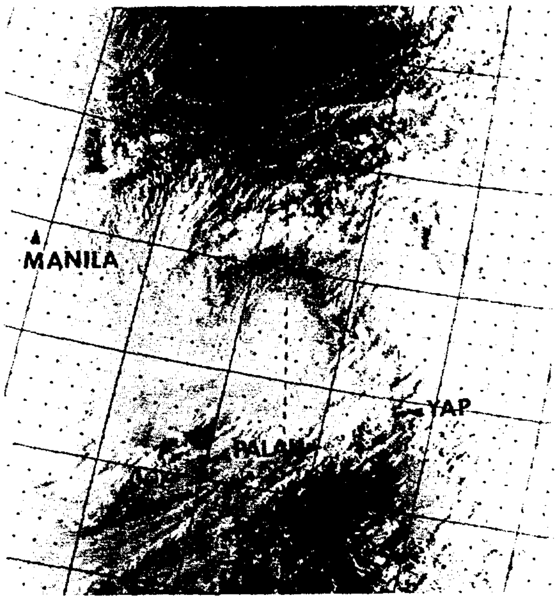


FIGURE 4-9. Babe at minimal typhoon strength and heading northward, 5 September 1977, 2155Z. (DMSP imagery)

FIGURE 4-10. Super Typhoon Babe at 130 kt (67 m/sec) intensity 250 nm (463 km) southeast of Ishigaki Jima, 8 September 1977, 0303Z. (DMSP imagery)

Up until the 080000Z warning, Babe was still forecast to cross Taiwan and then dissipate in mainland China prior to full recurvature. On the 7th at 1200Z, however, another upper air trough moved into northern China. This short wave additionally weakened the mid-tropospheric ridge over southeastern China. A low soon developed in this trough over Korea indicating the trough would move slowly and possibly deepen. This increased the probability that Babe would recurve much earlier than expected. This came to pass and as Taiwan was relieved, Okinawa and Japan now faced the fury of Babe. Aircraft and radar data showed Babe began recurvature to the northeast after the 8th at 0600Z and while weakening at a rate of 5 kt/6 hr (2.5 m/sec). Conditions of readiness were set for southern Japan and aircraft evacuated Kadena AB for appropriate "safe haven" locations (Fig. 4-11).

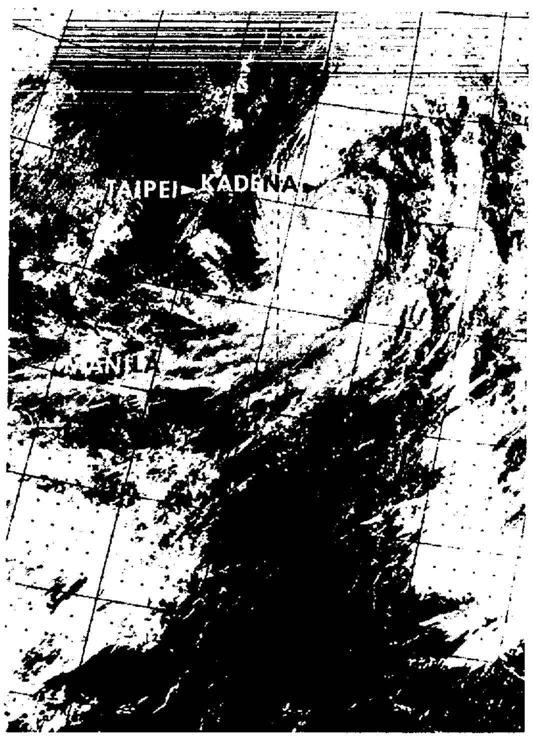


FIGURE 4-11. Typhoon Babe at 120 kt (62 m/sec) intensity, slowly weakening and accelerating northward, 9 September 1977, 0245Z. (DMSP imagery)

During Babe's north-northeastward transit, the upper air low which had formed over Korea moved south-southwestward, deepened and cut-off from the main upper air trough. This allowed ridging to the east and northeast of Babe to build east-west to the north of Babe and the cut-off low steering Babe toward Korea, and eventually Shanghai. Evidence of a Fujiwhara type effect between Babe's circulation and the cut-off low also appeared. Babe finally steered around the northern periphery of the cut-off low and hit the People's Republic of China just north of Shanghai on the 11th at 0000Z with surface winds of 65 kt (33 m/sec) (Fig. 4-12).

The greatest damage from super typhoon Babe occurred after she recurved and headed for Japan. Newspaper reports described Babe as "the worst typhoon to threaten Japan in 18 years". Babe struck the Japanese island of Okino-Erabu with winds of 135 kts (69 m/sec) injuring 45 people and destroying 1600 homes. Kadena AB recorded maximum sustained winds of 36 kt (19 m/sec) on the 9th and a peak gust of 60 kt (31 m/sec) at 091328Z. Babe also disrupted maritime activities sinking a Panamanian freighter with 16 reported dead or missing and damaging approximately 100 Japanese fishing vessels which sought safety in the East China Sea.

The overall forecast accuracy for super typhoon Babe was below average. However, the DoD operational impact was decreased by the use of forecast confidence probabilities appended to JTWC prognostic discussion bulletins and the many telephone conversations between JTWC and WESTPAC staff meteorologists. This was confirmed by operations staff personnel at the 1978 Tropical Cyclone Conference.

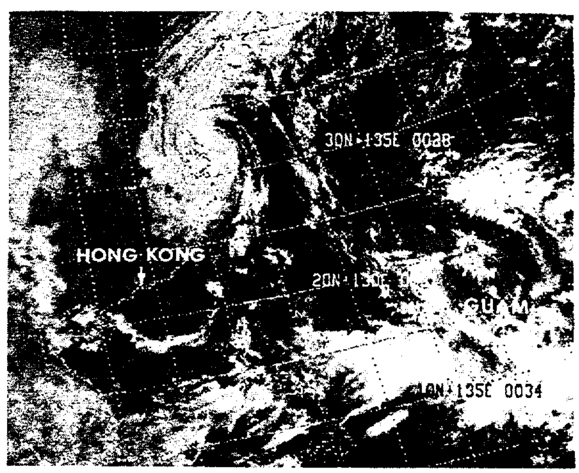
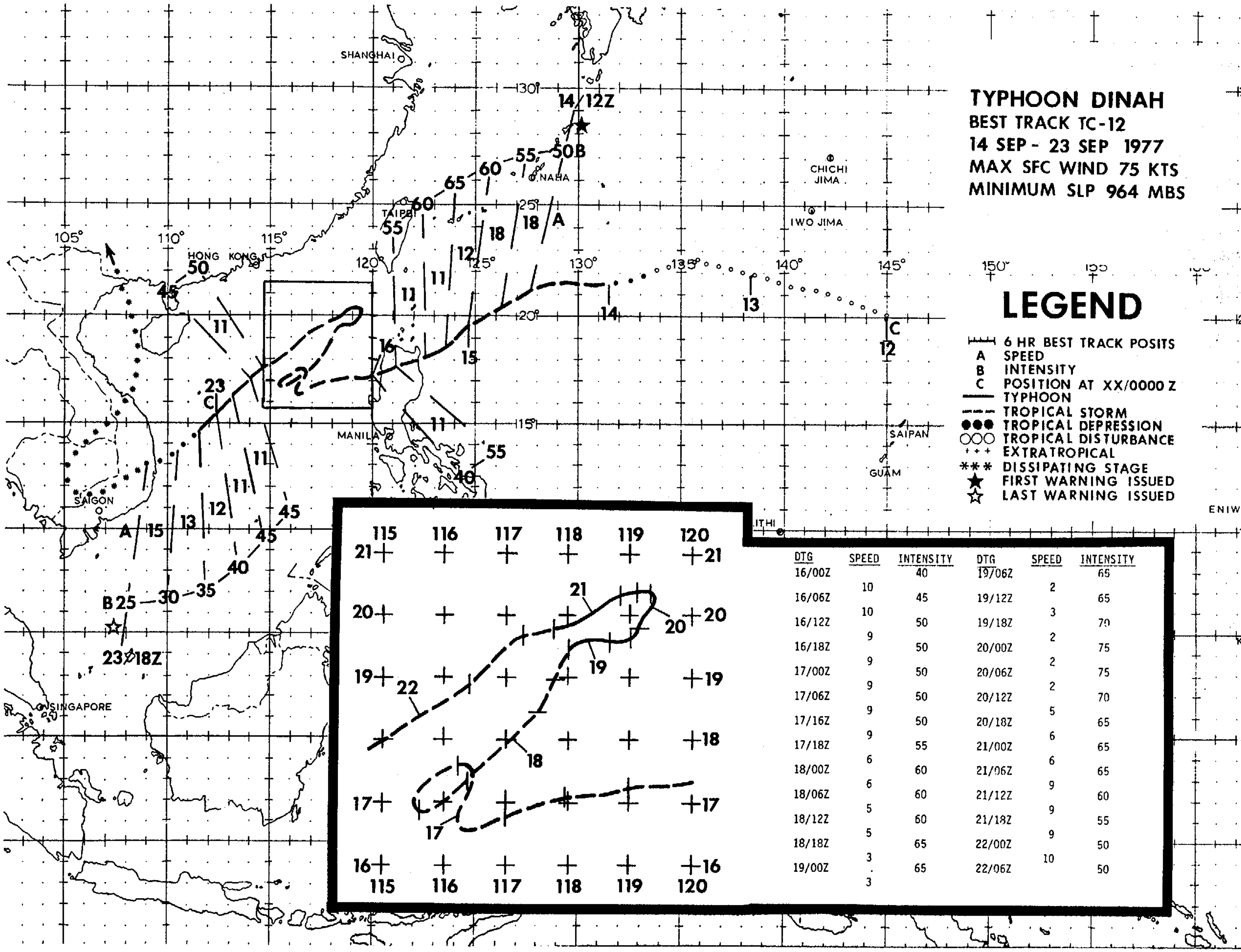


FIGURE 4-12. Typhoon Babe during landfall 60 nm (111 km) north of Shanghai, People's Republic of China, 11 September 1977, 0109Z. The monsoon trough extending from the Philippine to the Mariana Islands would soon spawn the next typhoon, Dinah. (NOAA-5 imagery from FLEWEAFAC Suitland, MD)



DTG	SPEED	INTENSITY	DTG	SPEED	INTENSITY
16/00Z		40	19/06Z		65
	10			2	
16/06Z		45	19/12Z		65
	10			3	
16/12Z		50	19/18Z		70
	9			2	
16/18Z		50	20/00Z		75
	9			2	
17/00Z		50	20/06Z		75
	9			2	
17/06Z		50	20/12Z		70
	9			5	
17/16Z		50	20/18Z		65
	9			6	
17/18Z		55	21/00Z		65
	6			6	
18/00Z		60	21/06Z		65
	6			9	
18/06Z		60	21/12Z		60
	5			9	
18/12Z		60	21/18Z		55
	5			9	
18/18Z		65	22/00Z		50
	3			10	
19/00Z		65	22/06Z		50
	3				

Dinah, the 5th typhoon of 1977, displayed the most unusual behavior. While over the South China Sea, the storm executed two hairpin turns and one loop before meandering over South East Asia during dissipation. Dinah's development, however, was a more normal sequence of events.

"Super" Typhoon Babe's extensive circulation system aided the monsoon trough to move north of its normal location. After Babe dissipated over eastern China, the monsoon trough extended from South East Asia to the Mariana Islands along 20 degrees north latitude. South of the trough, deep southwesterly flow produced localized gale force winds and extensive areas of thundershower activity. North of the trough, steady easterlies prevailed. Although the opposing currents produced considerable cyclonic shear and relative vorticity within the trough, the counter productive northeasterlies in the upper troposphere produced enough vertical shear to prevent significant tropical cyclone development. Meteorological satellite data during this 2nd week of September period showed several loosely organized areas of convection within the monsoon trough. On the 12th, synoptic data located a low level circulation center 400 nm (741 km) north of Guam. Maximum intensity near the center was estimated to be 20 kt (10 m/sec) while localized gale force winds continued within the southwest monsoon current to the southern and eastern periphery of the monsoon trough. (Islanders in the southwest flow could not believe there was not a tropical storm or typhoon nearby.)

The circulation center initially moved northwestward at an average speed of 16 kt (30 km/hr). Synoptic reports and satellite imagery revealed a tropical upper-tropospheric trough (TUTT) oriented east-west and just north of the position of the low to mid-level monsoon trough. By 1200Z on the 12th, a westward moving cyclone within the TUTT became positioned northeast of the surface disturbance. This orientation relieved much of the previously inhibiting vertical shear and provided an area of divergence aloft. This new flow pattern permitted the surface disturbance greater vertical growth and intensification. Satellite data soon identified a distinct vortex which separated from the areas of southwest monsoon cloudiness (Fig. 4-13). At 0100Z on the 14th, a formation alert was issued. The disturbance now moved westward as it entered the steering influence of an anticyclone over the East China Sea. Satellite pictures soon showed larger and better developed banding features. Since corresponding surface reports also indicated intensification, the first warning was issued for TD 12. Post analysis, however, found that the disturbance had achieved tropical depression intensity by 131800Z and tropical storm stage by 140000Z (Fig. 4-14). This was the period of maximum TUTT interaction. Because of the favorable conditions present during this time, another disturbance about 300 nm (556 km) north of Guam developed into Tropical Storm Emma.

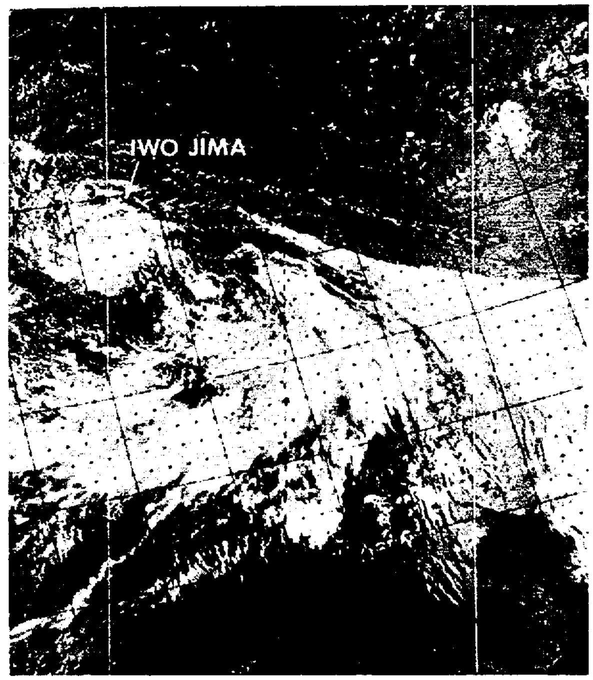


FIGURE 4-13. *Tropical Depression 12 (Dinah) 225 nm (417 km) southwest of Iwo Jima while breaking away from its place of origin, the monsoon trough, 12 September 1977, 2310Z. (NOAA-5 imagery)*

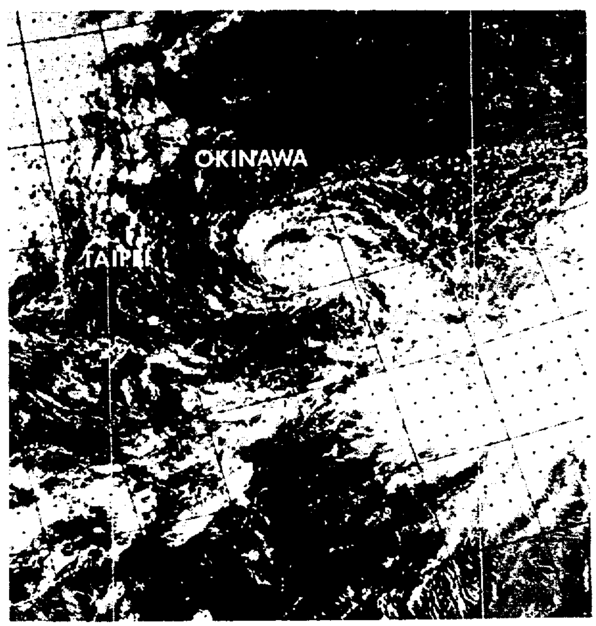


FIGURE 4-14. *Dinah at tropical storm stage intensifying in an interesting split configuration, 14 September 1977, 0023Z. Dinah appears to be composed of two, comma-shaped convective systems rotating cyclonically with a narrow zone of relative subsidence between them. (NOAA-5 imagery)*

As TD 12 grew and became Tropical Storm Dinah, the pressure gradient between the storm and the subtropical ridge increased. The associated easterly steering currents correspondingly increased and accelerated Dinah to a maximum speed of 19 kt (35 km/hr). An intensifying, mid-tropospheric high over eastern China was now the primary source of these easterlies. As this high pressure cell continued to build, Dinah was steered in a southwesterly direction towards the Republic of the Philippines. Forward speed decreased as the gradient slackened. Steady intensification continued as upper level outflow was well established in all quadrants. This trend persisted until Dinah reached minimum typhoon strength at 150600Z just 100 nm (185 km) off northern Luzon. With a maximum intensity of 55 kt (28 m/sec), the storm entered Luzon 35 nm (65 km) south of Escarpada Point at 151500Z. That evening Dinah passed near Tuguegarao, a station in northeastern Luzon which experienced 96 kt (49 m/sec) peak winds and a mean sea-level pressure of 977.0 mb.

Upon entering the South China Sea after 7 hours over land, Dinah weakened to 40 kt (21 m/sec), but quickly reintensified to 50 kt (26 m/sec) winds within 14 hours. Headed west-southwestward, Dinah entered an area of weaker steering currents. The dominating anticyclone over China was beginning to weaken and mid-latitude westerlies began extending southward. By the 17th, the continued weakening of steering currents caused the storm to slow to 9 kt (17 km/hr) movement.

For the next 4 days, Dinah exhibited unusual behavior. The weakening subtropical ridge over China broke down into a series of smaller high cells while the southwest monsoon deepened. Caught between these oscillating and opposing steering sources, Dinah abruptly turned northeast and then executed a loop during the 17th. As the southwest monsoon strengthened and became the dominant steering flow, the storm was directed northeastward toward Taiwan.

Intensification resumed as a result of the enhanced monsoon. The weakening subtropical ridge and increasing outflow aloft also contributed to Dinah's growth. By 181800Z, typhoon strength was again achieved. After being displaced north nearly 150 nm (218 km), movement slowed to 5 kt (9 km/hr) as Dinah's steering flow became less effective. By the 19th an advancing mid-latitude trough over China aided in steering Dinah eastward. Sustained winds of 65 kt (33 m/sec) persisted as satellite imagery at 191201Z revealed an eye. At 200000Z, Dinah reached a short-lived maximum intensity of 75 kt (39 m/sec) (Fig. 4-15). Ever since Dinah's origin, the southwest monsoon was the major feeding current. By 200600Z, this flow was being diverted into the beginnings of Tropical Storm Freda in the Philippine Sea and Dinah began to weaken.

As the mid-latitude trough advanced over China, it did not dig south as forecast and a large high pressure area built in behind it. In response, Dinah did not continue eastward in advance of the trough; it slowed to 2 kt (3.7 km/hr), turned westward, then southwestward being influenced by the intensifying high over China. Dinah was the first storm to be directly affected by an early autumn surge in the northeast monsoon.

The northeasterlies from the strong high over China controlled Dinah's movement for the next 2 days. Diminishing moist southwesterlies and increasing dry northeasterlies steadily weakened the storm. Dinah accelerated southwestward and reached south Vietnam as a weak tropical depression at 231700Z. JTWC's last warning was issued one hour later.

After landfall, Dinah, in its dissipating stage, persisted for 4 days. Tropical Storm Freda and the weakening of the northeast monsoon were the controlling agents in the last days of Dinah's unusual track. After crossing the South China Sea, Freda entered southern China drawing the southwest monsoon northward. Once again embedded in a southwest steering current, TD 12 (Dinah) journeyed northward through Cambodia, northeastward over the Gulf of Tonkin then northward into southern China and finally dissipated.

Dinah's sweep across northern Luzon caused loss of lives and property. Floods and landslides alone caused 15 deaths and 11 missing. Although Dinah remained a safe distance from mainland China while jogging unpredictably over the South China Sea, Hong Kong displayed the Stand By Signal No. 1 for a record 124 hours and 40 minutes.

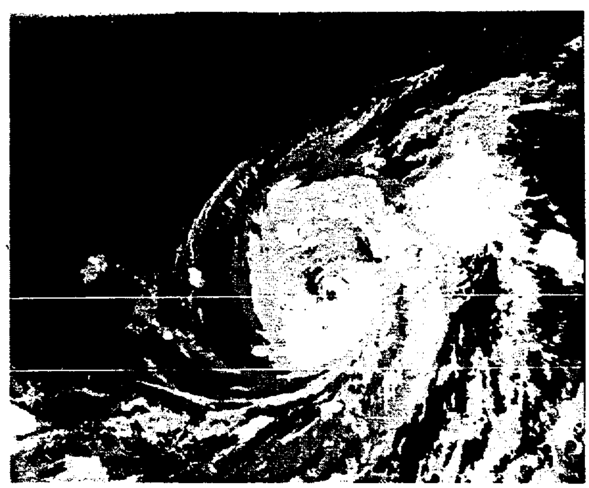
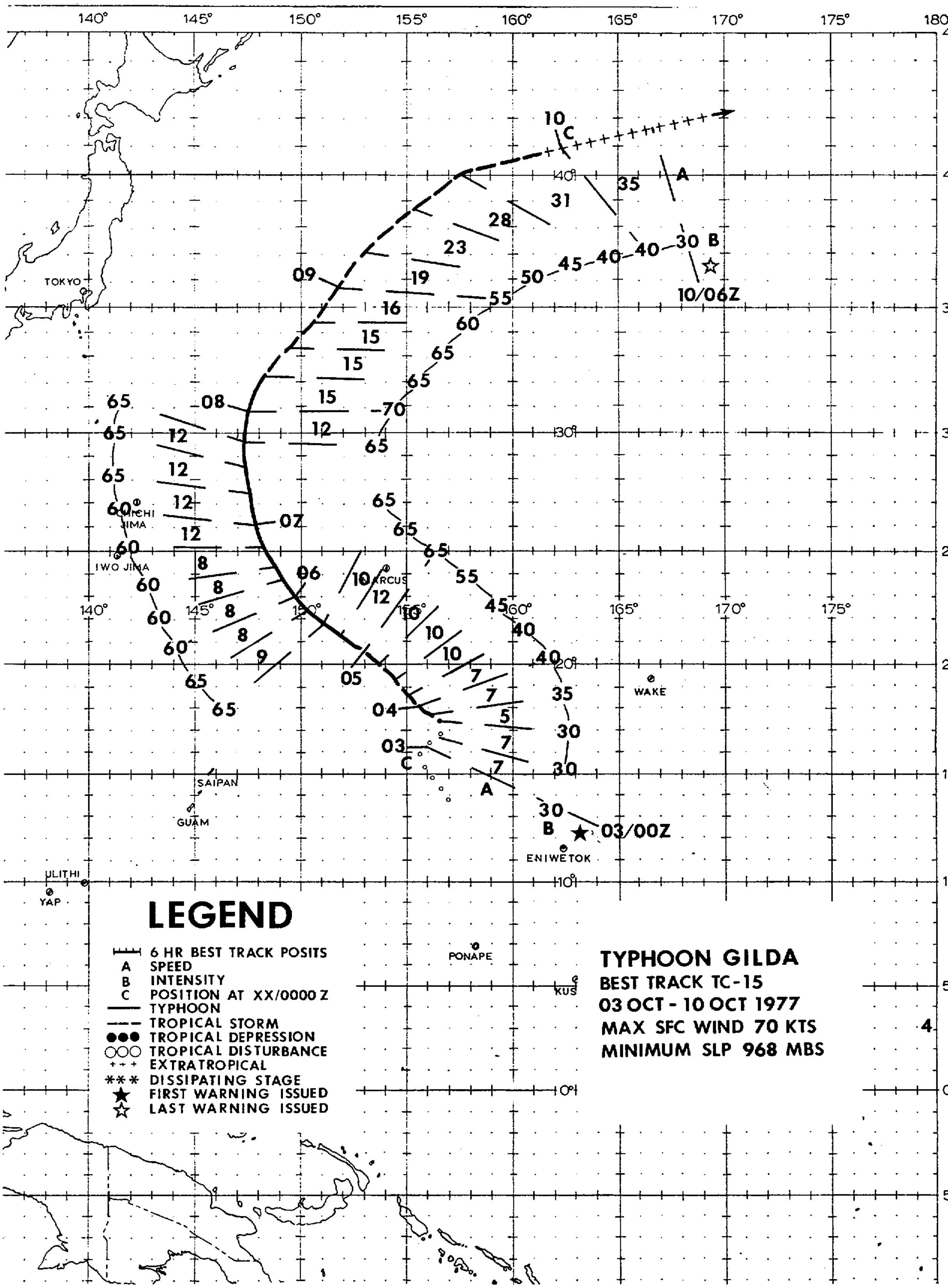


FIGURE 4-15. Infrared, threshold photograph of Typhoon Dinah at maximum intensity of 75 kt (39 m/sec), 19 September 1977, 2310Z. This special product consolidates the thermal range into four slices (gray shades) with white being coldest and black warmest.
Black: greater than 253°K; dark gray: 253° to 233°K; light gray: 233° to 213°K; white: less than 213°K. (DMSP imagery from Det 5, 1WW, Clark AB, RP)


LEGEND
6 HR BEST TRACK POSITS
A SPEED
B INTENSITY
C POSITION AT XX/0000 Z
TYPHOON
TROPICAL STORM
TROPICAL DEPRESSION
TROPICAL DISTURBANCE
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
TYPHOON GILDA
BEST TRACK TC-15
03 OCT - 10 OCT 1977
MAX SFC WIND 70 KTS
MINIMUM SLP 968 MBS
TOKYO
CHICHI JIMA
IWO JIMA
MARCUS
SAIPAN
GUAM
ULITHI
YAP
WAKE
ENIWETOK
PONAPE
KUS
03/00Z
10/06Z
140°
145°
150°
155°
160°
165°
170°
175°
180°
45°
40°
35°
30°
25°
20°
15°
10°
5°
0°

On the 1st of October, a large area of heavy convection, 300 nm (556 km) in diameter, was detected by satellite approximately 325 nm (600 km) north of Ponape. Synoptic data indicated a weak surface circulation in the vicinity. The system, which would later become Typhoon Gilda, was observed to be moving northward toward a weakness in the mid-tropospheric subtropical ridge.

On the 2nd of October, a Tropical Cyclone Formation Alert was issued as satellite data indicated increased organization and upper level outflow. Further intensification was expected due to the existence of an upper level trough to the northwest.

Aircraft reconnaissance on the morning of the 3rd reported 38 kt (20 m/sec) winds at the 1500 foot (441 m) flight level. Based on this data and the assessed good potential for further intensification, the first warning was issued on TD 15 at 0000Z on the 3rd.

For the next 18 hours the tropical depression moved erratically toward the north at a speed of 5 kt (9.3 km/hr). During the 3rd, the mid-tropospheric subtropical ridge northeast of TD 15 began to build toward the west. Late on the 3rd, TD 15 responded and began to move toward the northwest. Simultaneously, the tropical depression began to interact with a cyclonic cell in the Tropical Upper Tropospheric Trough (TUTT) located to the depression's northwest. Divergent southwesterlies aloft, on the southeast periphery of the upper level cyclonic cell, enhanced the outflow of TD 15 and by 1800Z on the 3rd the system had intensified to tropical storm intensity.

During the 4th, Tropical Storm Gilda continued to intensify as it accelerated to 12 kt (22 km/hr) on its northwestward track. Reconnaissance aircraft on the afternoon of the 5th indicated 80 kt (41 m/sec) winds at its 700 mb flight level, and observed that the central pressure of Gilda had fallen to 974 mb, a 15 mb drop in 11.5 hours. Using this information, Gilda was upgraded to typhoon at 0600Z.

During the past 36 hours, a mid-tropospheric, short wave trough moved eastward from eastern China toward Japan, and began to deepen. By the 5th this trough had moved east of northern Japan, and had dug sufficiently equatorward to sever the subtropical ridge north of Gilda. By the afternoon of the 6th, the typhoon had acquired a north-northwestward track toward the weakness in the ridge. At 0622Z, aircraft reconnaissance showed that the central pressure had risen to 986 mb. Consequently, the 0600Z warning was amended and Gilda was downgraded to a Tropical Storm. The weakening, however, was short lived; 24 hours later she had again attained typhoon intensity. At 1500Z on the 7th Gilda passed through the weakness in the subtropical ridge and shortly thereafter began recurving toward the north-northeast. As frequently observed with October tropical cyclones, Typhoon Gilda continued to intensify after recurvature. She attained her peak intensity of 70 kt (36 m/sec) on the 8th when aircraft at 0325Z reported the typhoon's minimum sea level pressure of 968 mb(Fig. 4-16).

By the night of the 8th, Gilda had again weakened to tropical storm strength, and had taken a northeast heading around the northwestern periphery of the mid-tropospheric high cell. During the subsequent 36 hours, the tropical storm accelerated rapidly toward the east-northeast and weakened at a rate of 5 kt (2.6 m/sec) per 6 hours. On the morning of the 10th, Gilda became extratropical, moving toward the east-northeast at more than 30 kt (55 km/hr).

During her eight day span, the closest point of approach to land was 220 nm (407 km) when she passed southwest of Marcus Island on the evening of October 5th. On the ocean, ships stayed well away from Gilda's strong winds. As a result, Gilda claimed no loss of life or damage to property.

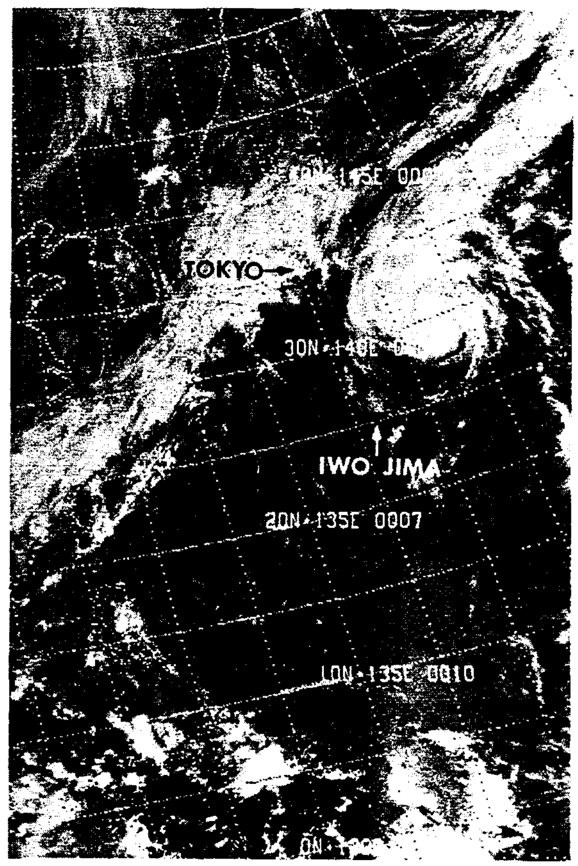
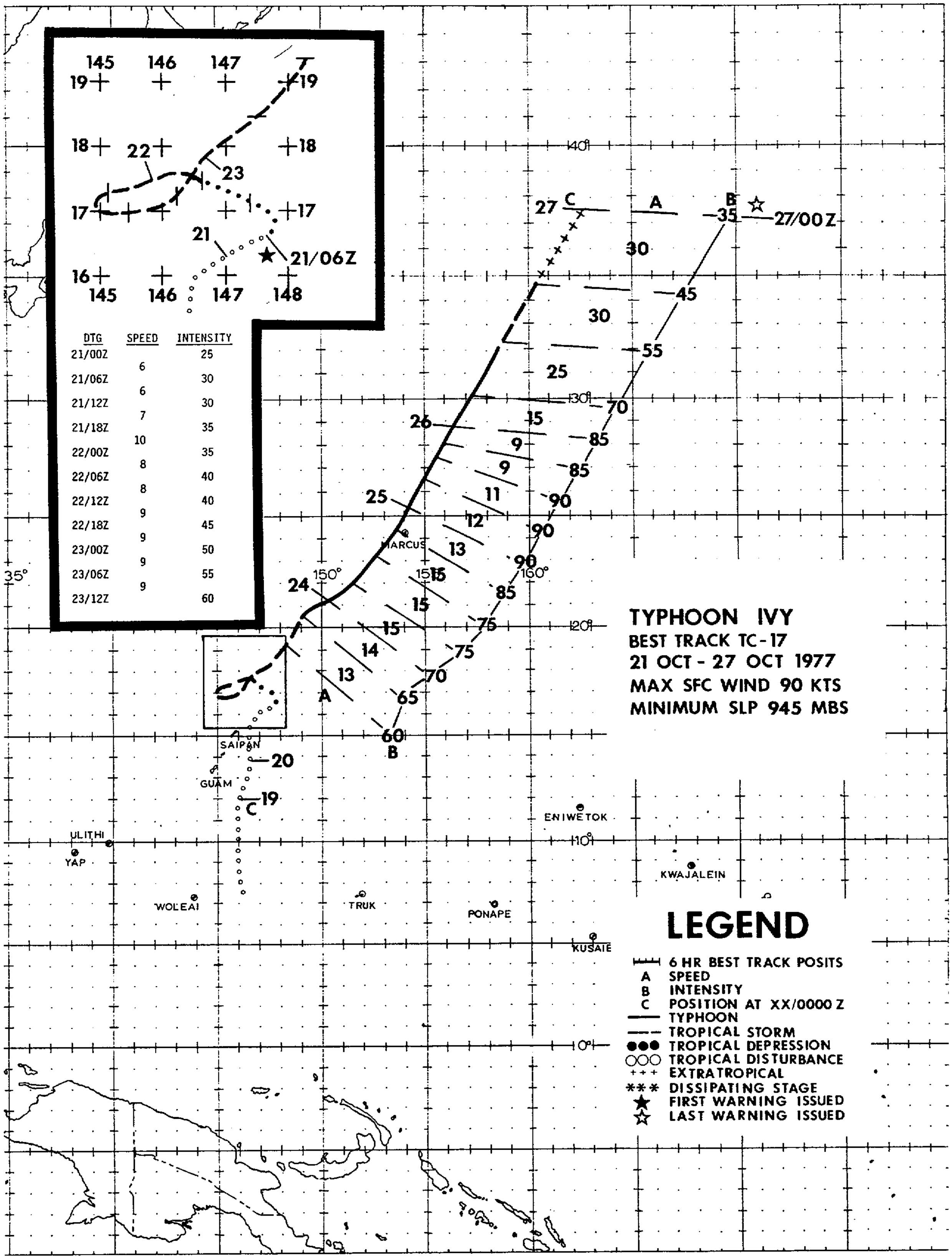


FIGURE 4-16. Typhoon Gilda at maximum intensity of 70 kt (36 m/sec) during recurvature, 7 October 1977, 2343Z. (NOAA-5 imagery from FLEWEAFAC Suitland, MD)



TYPHOON IVY
BEST TRACK TC-17
21 OCT - 27 OCT 1977
MAX SFC WIND 90 KTS
MINIMUM SLP 945 MBS
LEGEND
6 HR BEST TRACK POSITS
A SPEED
B INTENSITY
C POSITION AT XX/0000 Z
TYPHOON
TROPICAL STORM
TROPICAL DEPRESSION
TROPICAL DISTURBANCE
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
21/06Z
27/00Z
DTG SPEED INTENSITY
21/00Z 25
6
21/06Z 30
6
21/12Z 30
7
21/18Z 35
10
22/00Z 35
8
22/06Z 40
8
22/12Z 40
9
22/18Z 45
9
23/00Z 50
9
23/06Z 55
9
23/12Z 60
SAIPAN
GUAM
ULITHI
YAP
WOLEAI
TRUK
PONAPE
MARCUS
ENIWETOK
KWAJALEIN
KUSAIE

Ivy, the 7th typhoon of 1977, originated from an easterly wave. It was first detected by synoptic data moving westward over the Marshall Islands on the 14th of October. Within 24 hours it entered an area of increased low level convergence associated with the near equatorial trough (NET), intensified, and developed a surface circulation. For the next 8 days it remained within the NET before breaking loose.

The development of Ivy was also aided by the movement of Tropical Storm Harriet, which was also embedded in the NET. TS Harriet moved northward through the Philippine Sea displacing the NET northward. This northward shift allowed for an increase in favorable conditions for intensification. By the 19th the developing cyclone (Ivy) was receiving most of the low level, southwesterly flow that was previously supplied to the now weakening Harriet (Fig. 4-17). The next day satellite data indicated that the disturbance's convective activity and organization had increased while surface reports indicated that the central pressures were steadily falling. JTWC, therefore, issued a formation alert at 200126Z.

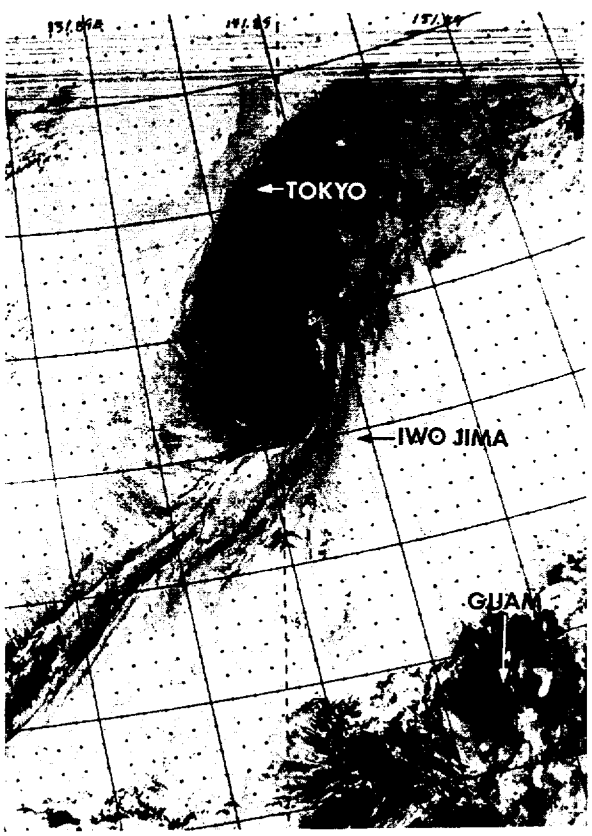


FIGURE 4-17. Infrared photograph of Ivy in the formative stage near Guam with Tropical Storm Harriet at maximum intensity of 55 kt (28 m/sec), 19 October 1977, 1014Z. (DMSP imagery)

Upper tropospheric, synoptic data from the morning of the 21st indicated that the outflow pattern above the alert area was continuing to strengthen. An aerial reconnaissance investigation on the afternoon of the 21st detected an organized surface cyclonic circulation with a 996 mb central pressure. Reconnaissance data further indicated that the disturbance was moving northward just east of the Mariana Islands. Along with supportive satellite data, the first warning on TD 17 was issued at 210600Z.

On the morning of the 20th, TD 17 began moving through a break in the subtropical ridge previously opened by Harriet. This was also an area of weak and variable steering currents. From the morning of the 21st to the evening of the 22nd. there was a lack of any definitive, middle tropospheric steering flow which resulted in the erratic movement of the storm. For 36 hours TD 17 meandered and then looped before heading northeastward (Fig. 4-18).

During the formative stages of TD 17, upper tropospheric, synoptic and satellite data indicated the presence of a weak tropical upper tropospheric trough (TUTT) to the northeast. As the disturbance reached tropical depression intensity, data indicated that a low in the TUTT had developed. The establishment of the TUTT low in this region allowed for an increase in the advection of mass away from the storm. This allowed for further intensification and the depression to reach tropical storm intensity during the course of its loop. Aircraft reconnaissance

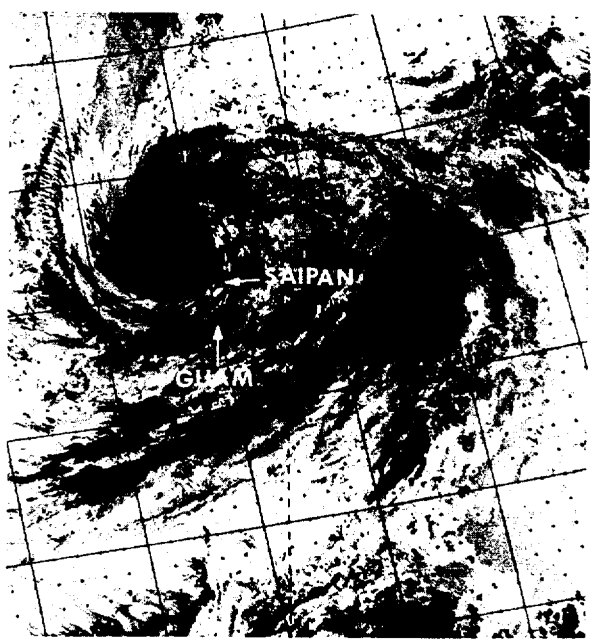


FIGURE 4-18. Infrared photograph of Ivy with 40 kt (21 m/sec) winds executing a cyclonic loop, 22 October 1977, 0923Z. (DMSP imagery)

on the 21st at 1545Z observed a maximum flight level, 700 mb, wind of 38 kt (20 m/sec) associated with the storm. Based on this data TD 17 was upgraded to Tropical Storm Ivy at 211800Z.

From the evening of the 22nd, the storm began to accelerate and move northeastward in response to an eastward moving short-wave trough in the mid-latitude westerlies. During this period the TUTT began to intensify. This created an upper air regime which was favorable for further intensification. On the morning of the 24th Ivy reached typhoon intensity. Reconnaissance aircraft at 0341Z recorded a central pressure of 967 mb and observed sustained, 700 mb winds of 75 kt (39 m/sec) about an eye 30 nm (56 km) in diameter.

After reaching typhoon intensity, Ivy continued to the northeast. This movement caused the storm to pass 20 nm northwest of Marcus Island (WMO 47991) at 241930Z. Marcus reported a sustained 70 kt (36 m/sec) at 1800Z and 111 kt (57 m/sec) gusts at 2100Z. As Ivy continued northeastward, further intensification took place. After establishment of other TUTT lows to the north and south of the storm, a maximum strength of 90 kt (46 m/sec) was reached on the 25th (Fig. 4-19). New aircraft data reported a well defined eye with a 945 mb central pressure.

Typhoon Ivy maintained maximum intensity for 12 hours. The continued northward displacement was due to the increasing influence of a quasi-stationary upper-level trough east of Japan. This also caused the storm to enter a cooler environment which began to degrade Ivy into an extratropical system. As a result, the last warning was issued at 261800Z. Ivy quickly weakened and became extratropical along a cold front.

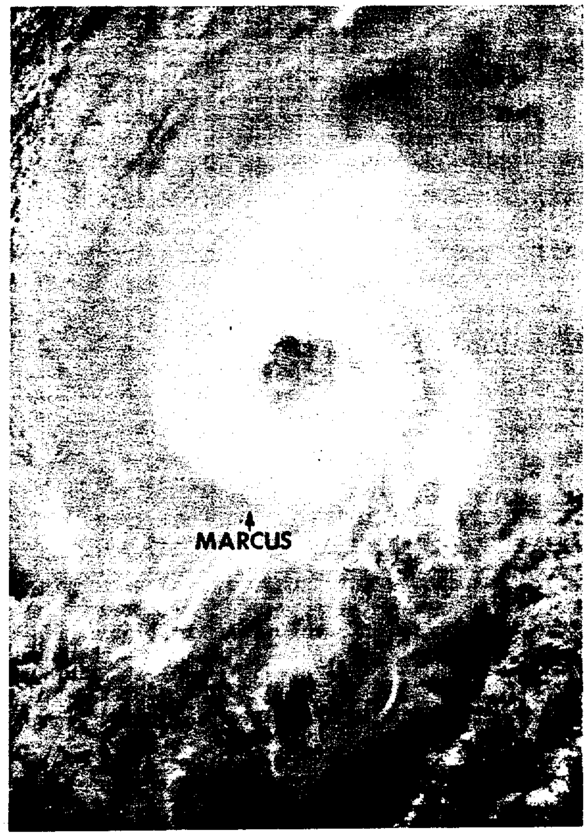
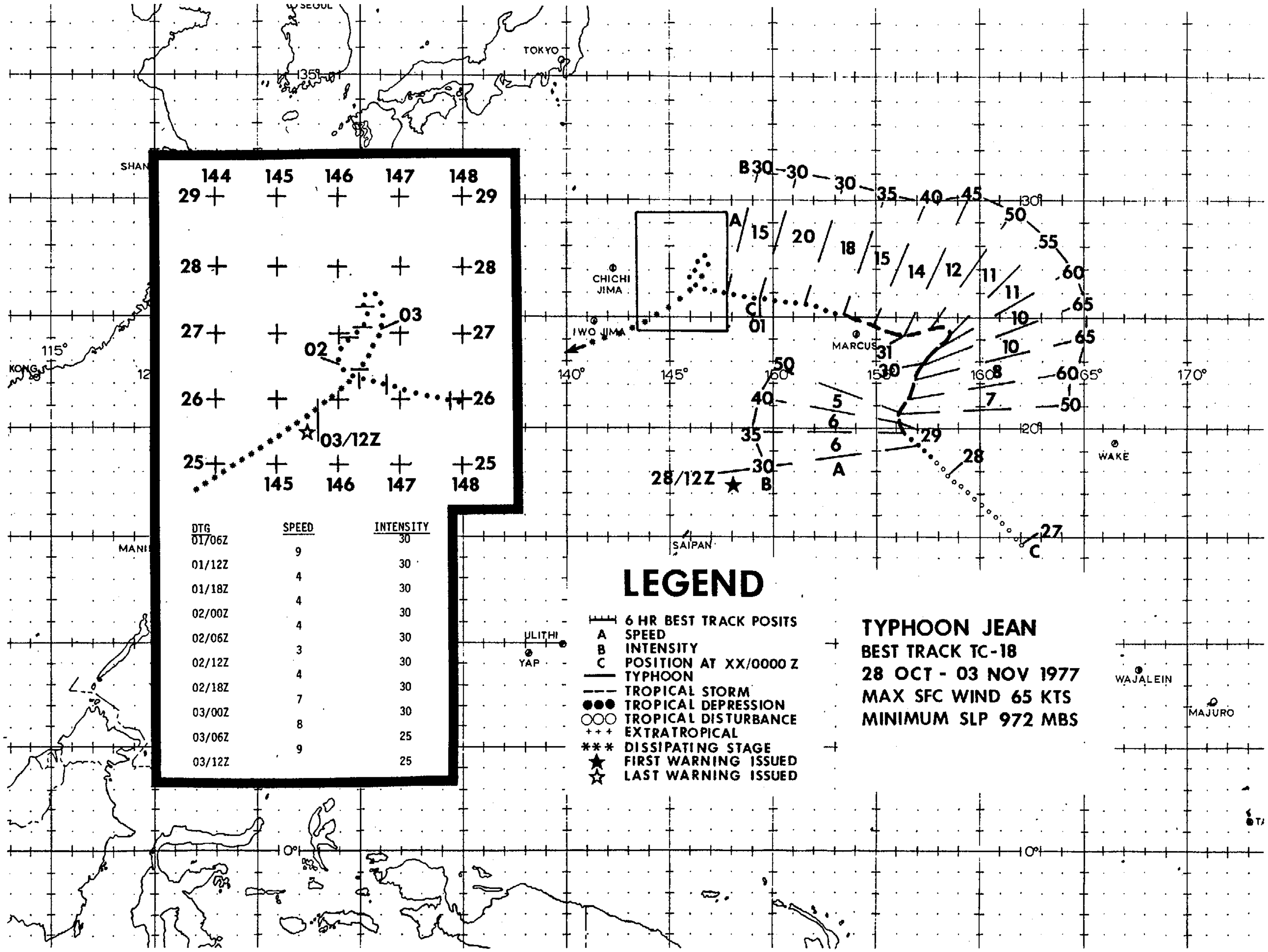


FIGURE 4-19. Typhoon Ivy displaying a well defined eye at its maximum intensity of 90 kt (46 m/sec), 25 October 1977, 0106Z. (DMSP imagery)



TYPHOON JEAN
BEST TRACK TC-18
28 OCT - 03 NOV 1977
MAX SFC WIND 65 KTS
MINIMUM SLP 972 MBS

DTG	SPEED	INTENSITY
01/06Z		30
01/12Z	9	30
01/18Z	4	30
02/00Z	4	30
02/06Z	4	30
02/12Z	3	30
02/18Z	4	30
03/00Z	7	30
03/06Z	8	25
03/12Z	9	25

Jean, the 18th tropical cyclone of 1977, established two season records; first, as the shortest-lived typhoon of the season and second, as the only tropical cyclone of 1977 for which a formation alert was not issued prior to the initial warning. Jean was first observed on satellite imagery as a weak disturbance located some 200 nm (371 km) southeast of Kwajalein Atoll at 2128Z on the 24th of October. While moving northwestward at 14 kt (26 km/hr), the disturbance was included on JTWC's Significant Tropical Weather Advisory (ABEH PGTW) for the next several days. Located downstream of an upper tropospheric trough axis in a difluent area aloft, the disturbance was in a favored position for development. By 1200Z on the 27th, an upper tropospheric outflow center (200 mb) was analyzed over the surface position further supporting development.

Due to the presence of a ship in close proximity to the cyclone, the initial warning on Tropical Depression 18 was issued at 1200Z on the 28th with an intensity of 30 kt (15 m/sec) and a northwest movement at 14 kt (26 km/hr). Satellite data over the next 6 to 12 hours indicated an intensity increase and at 1800Z on the 28th the depression was upgraded to tropical storm status. At this same time, Jean was beginning to show a more northward trend and had slowed appreciably to a speed of 6 kt (11 km/hr). The more northward thence north-northeastward track was attributed to upper- and mid-tropospheric level steering influences which were dominant above the easterly steering flow near the surface and in the lower troposphere. Because the steering currents at various levels were not acting in conjunction, a slowing trend in forward movement was noted.

At 0513Z on the 29th, reconnaissance aircraft penetrated the storm and observed surface winds near 60 kt (31 m/sec) and also reported that an eye was beginning to form. Satellite imagery at 0905Z on the 29th (Fig. 4-20) further supported the aircraft's observed intensification; consequently, at 1800Z on the 29th, Jean was upgraded to a typhoon. Satellite positioning also dictated a more north-northeastward track. Jean maintained minimum typhoon intensity for the next 6 hours through the 300000Z warning thereby establishing the aforementioned record as the shortest-lived typhoon of the season.

Post analysis revealed that beyond the 300000Z position Jean began to react to the effects of very strong vertical shear. At the surface and at low-tropospheric levels, steering flow was strong easterly around the southern periphery of the subtropical ridge. Steering flow at mid- and upper-tropospheric levels was strong west-southwesterly. Under this hostile regime, Jean began to weaken and had made her furthest northeastward incursion by 1200 on the 30th with 55 kt (28 m/sec) intensity. Satellite data on the 30th showed an exposed low-level circulation center to the west of the area of major convective activity. Jean began to weaken rapidly and move west and then west-northwest in response to the east/east-southeasterly steering at low tropospheric levels. Figure 4-21 depicts

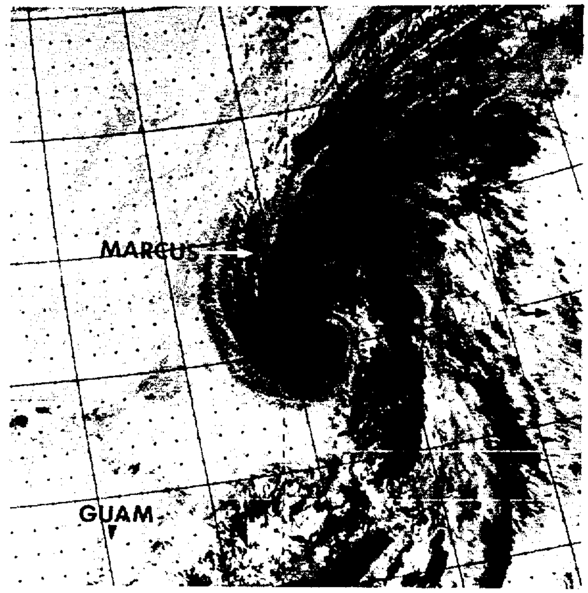


FIGURE 4-20. Infrared photograph of Jean at 55 kt (28 m/sec) intensity tracking north-northeastward, 29 October 1977, 0905Z. (DMSP imagery)

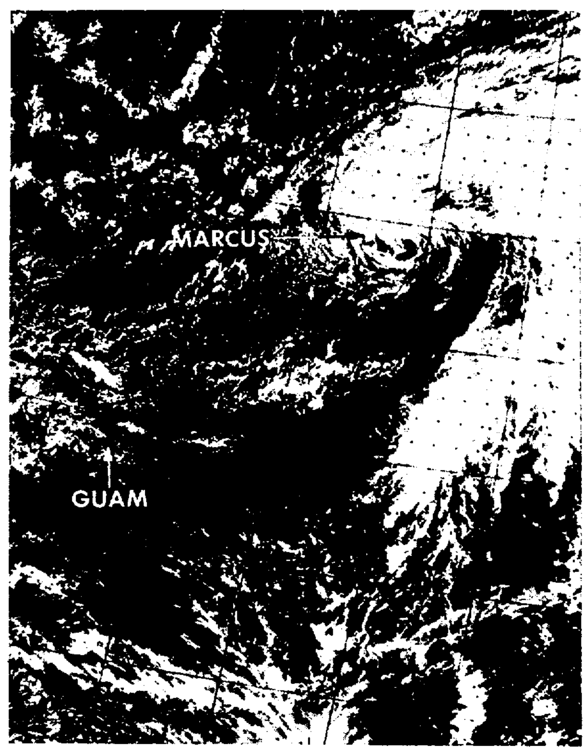


FIGURE 4-21. Exposed low level circulation of Tropical Storm Jean at 40 kt (21 m/sec) intensity during westward acceleration, 31 October 1977, 0102Z. (DMSP imagery)

the low level circulation center with the major convection sheared off to the east. Figure 4-22 is a graphic depiction of Jean's passage north of Marcus Island through three-hourly synoptic reports.

JTWC issued its expected final warning on TD 18 (formerly Tropical Storm Jean) at 1200Z on the 31st with a forecast dissipation within 12 hours. The low level circulation was closely monitored via satellite for signs of reintensification for the next 24-36 hours. By 2323Z on the 1st of November, the disturbance began to show an improved satellite signature with an increase in convective activity. TD 18 was reactivated and a warning was issued at 0000Z on the 2nd of November. AT this time, TD 18 began meandering northward at 3 to 4 kt (5.5 to 7.5 km/hr) and showed an intensity of 30 kt (15 m/sec). For the next 12 to 24 hours, the system executed a looping movement and by 1450Z on the 2nd satellite data again showed the effects of strong vertical shear with an exposed low level circulation again visible to the west of the main convection. Once sheared off, the low level circulation responded to low tropospheric, northeasterly flow around the southeastern periphery of a large anticyclone centered over the Sea of Japan. The final warning was issued at 031200Z with dissipation forecast by 031800Z. The low level circulation center continued tracking to the southwest and then west-southwest remaining weak and visible on satellite imagery until 0019Z on the 6th of November.

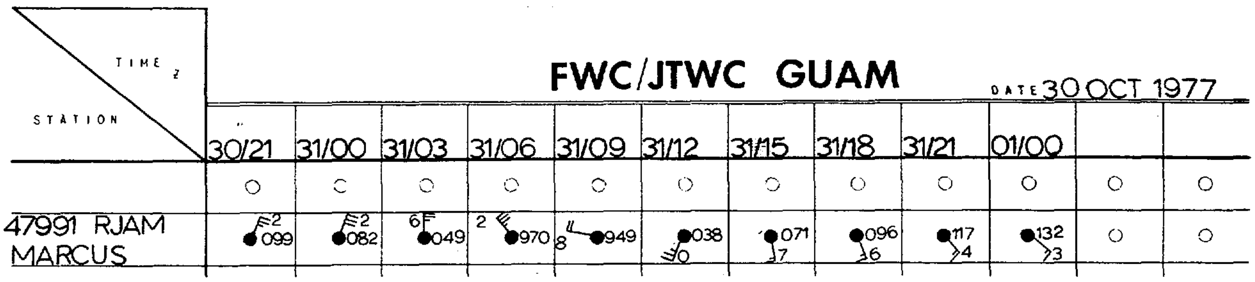
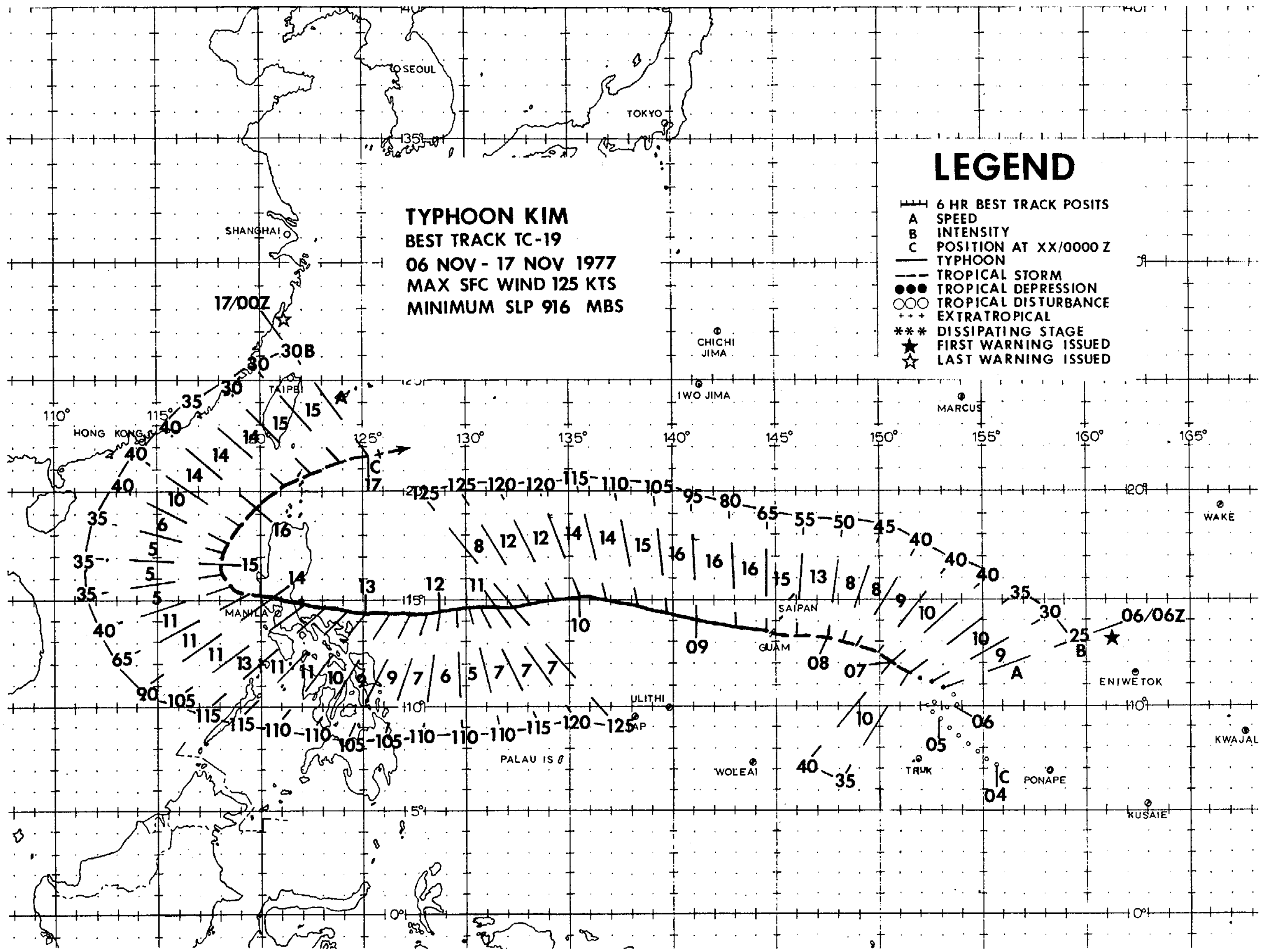


FIGURE 4-22. *Three-hourly synoptic surface observations at Marcus Island during the passage of Jean.*


TYPHOON KIM
BEST TRACK TC-19
06 NOV - 17 NOV 1977
MAX SFC WIND 125 KTS
MINIMUM SLP 916 MBS
LEGEND
6 HR BEST TRACK POSITS
A SPEED
B INTENSITY
C POSITION AT XX/0000 Z
TYPHOON
TROPICAL STORM
TROPICAL DEPRESSION
TROPICAL DISTURBANCE
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
SEOUL
TOKYO
SHANGHAI
TAIPEI
HONG KONG
MANILA
CHICHI JIMA
IWO JIMA
MARCUS
WAKE
SAIPAN
GUAM
ULITHI
YAP
PALAU IS
WOLEAI
TRUK
PONAPE
ENIWETOK
KWAJAL
KUSAIE
17/00Z
06/06Z

Kim, the 9th typhoon of the season, originated in an active near-equatorial trough (NET), which extended through the western Marshall Islands. Weak surface circulations existed within this trough near Ponape and Kwajalein. During the 2nd of November, this activity had consolidated into a single surface circulation 100 nm (185 km) southwest of Ponape with a central pressure of 1007 mb. The disturbance began moving northwestward within the NET at approximately 6 kt (11 km/hr).

At 2155Z on the 3rd, satellite first fixed the disturbance and estimated the winds to be 20 kt (10 m/sec). A circulation center was located 150 nm (270 km) northwest of Ponape. With the weekend approaching, a formation alert was issued on the 4th as satellite and synoptic data indicated a strengthening surface circulation. Aircraft reconnaissance the next day found a central pressure of 1007 mb and estimated a maximum surface wind of 20 kt (10 m/sec). As the disturbance continued northwestward toward a broad, relative weakness in the strong mid-tropospheric subtropical ridge, synoptic and satellite data still indicated no significant development. Potential for development remained fair to good and the formation alert was therefore extended for 24 hours. A second aircraft investigation on the 6th fixed the system with a 1004 mb central pressure and maximum surface winds of about 25 kt (13 m/sec). Kim's first warning as TD 19 was issued at 0600Z on the 6th. The system was upgraded to Tropical Storm Kim just 12 hours later.

Kim next turned toward Guam at a speed of approximately 10 kt (19 km/hr). Slow intensification occurred during the next 48 hours due to the dominating presence of the strong subtropical ridge to the north. A short wave trough in the upper tropospheric westerlies also hampered rapid development by restricting outflow to the north of Kim. However, after the trough passed by, outflow aloft steadily strengthened. A deepening long wave trough over eastern Asia was now beginning to weaken the subtropical ridge which was previously suppressing Kim's low level development. Satellite data at 080204Z indicated increased organization (Fig. 4-23). Kim began intensifying at the rate of 30 kt (15 m/sec) in 24 hours and the central pressure dropped 22 mb in a 24 hour period.

Kim passed directly over Guam on 8 November between 1020Z and 1235Z approaching Guam from the east-southeast, moving westward over the island, and exiting toward the west-northwest. The eye entered with a circular configuration and exited with an elliptical configuration. Figure 4-24 depicts eye passage as seen by radar while Figure 4-25 displays the barograph trace recorded at Andersen AFB, Guam. The duration of the eye passage over the island lasted up to 1 hour and 10 minutes near the center of the storm track. The peak gust recorded was 77 kt (40 m/sec) on Nimitz Hill. The greatest damage was in the southern end of the island where 22 homes were damaged or destroyed (Figs. 4-26 and 4-27). Fortunately, no lives were lost on Guam.

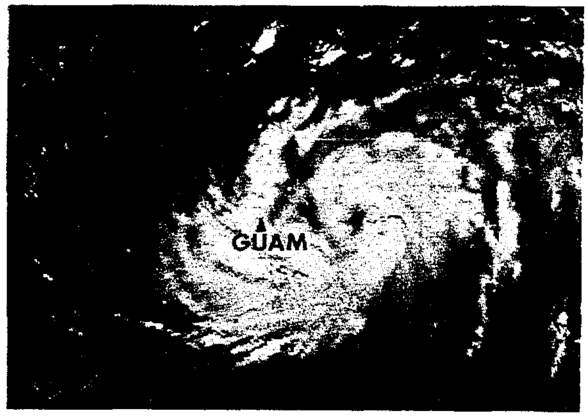


FIGURE 4-23. Kim at 50 kt (26 m/sec) intensity, rapidly intensifying, and heading for Guam, 8 November 1977, 0204Z. (DMSP imagery)

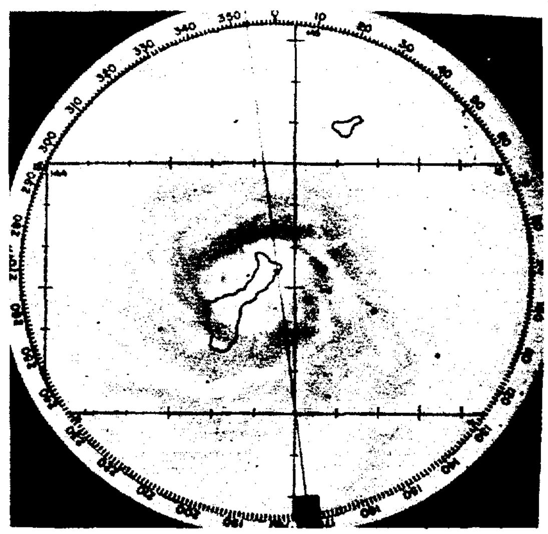


FIGURE 4-24. Air Weather Service radar presentation of Kim at 60 kt (31 m/sec) intensity with the eye over Guam, 8 November 1977, approximately 1130Z. (Photograph courtesy of Det 2, 1WWg, Andersen AFB, Guam.)

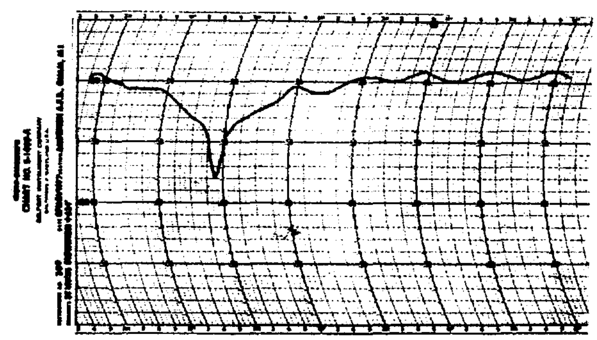


FIGURE 4-25. Reproduction of the barograph trace from Andersen AFB, Guam during eye passage of Kim. The center passed approximately 8 nm (15 km) south of Andersen AFB.

FIGURE 4-26. *Kim's nearly typhoon strength winds battered the exposed, coastal village of Umatac. (Photograph courtesy of P. J. Ryan of the Pacific Daily News.)*

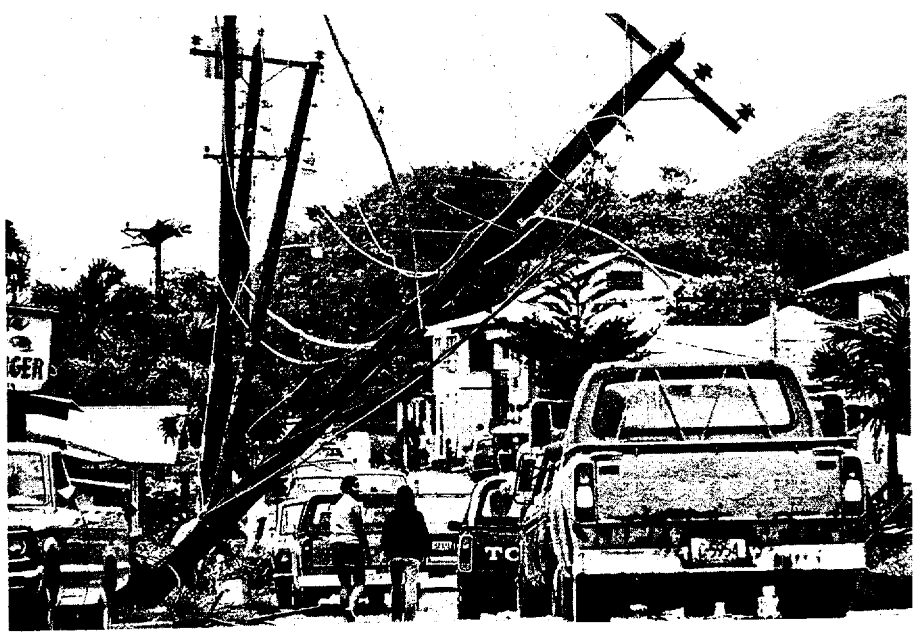


FIGURE 4-27. *Although damage was slight on most of the island, Umatac Village on the southwest coast did not fare so well. (Photograph courtesy of P. J. Ryan of the Pacific Daily News.)*

Kim was upgraded to typhoon strength at 2200 local on the 8th just after exiting Guam. For the next 48 hours the storm continued to intensify. The subtropical ridge continued to slowly weaken throughout this period, but it maintained sufficient strength to steer Kim in a west-northwestward direction. Moving at approximately 15 kt (28 km/hr), Kim advanced toward another weakness in the ridge located between two subtropical high pressure cells. As the tropospheric steering flow weakened, forward speed decreased and intensification increased. When Kim was nearest this weakness within the ridge, she attained a speed minimum, 5 kt (9 km/hr), and an intensity maximum of 125 kt (64 m/sec) (Fig. 4-28).

Kim now took on a more westward track as she came under the influence of the next subtropical high cell. Kim was also gradually approaching a deep, quasi-stationary, upper tropospheric trough over Asia. This trough produced strong southwesterly flow which began to restrict outflow ahead of Kim resulting in decreasing intensity. At the same time, a deepening low cell in the Tropical Upper Tropospheric Trough (TUTT) was slowly approaching Kim from the east. This low cell eventually came in position to enhance upper level outflow. A secondary maximum intensity, 120 kt (62 m/sec), was achieved from this interaction.

Kim was soon headed straight for central Luzon (Fig. 4-29). Landfall occurred on the 13th causing extensive damage on the coastline with winds of 115 kt (59 m/sec). The storm passed about 35 nm (65 km) north of Manila and 5 nm (9 km) south of Clark AB.

The typhoon exited into the South China Sea 7 hours after landfall with an intensity of 65 kt (33 m/sec). This amount of weakening is in good agreement with the latest climatological studies of intense typhoons crossing Luzon. Even though the South China Sea still had warm sea surface temperatures, Kim never reintensified due to strong, cool northeast monsoon flow entraining into the storm environment. By this time the mid-latitude westerlies had sufficiently weakened the subtropical ridge which separated Kim from the westerlies. Rapidly decelerating, Kim turned northward in response to the steady southwesterly steering flow being produced by an approaching upper tropospheric trough. Increased upper level shearing began the storm's extratropical transformation. Turning northward, Kim entered deeper westerly flow and was accelerated northeastward through the Bashi Channel. Kim became an extratropical system by 0000Z on the 17th and merged with a weak frontal system east of Taiwan.

Kim was a long-lived storm with 44 warnings issued during a 12 day period. Guam sustained moderate property damage when Kim crossed the island as a strong tropical storm. Luzon, however, reported 55 drownings due to widespread flooding. In Manila, a fire in a hotel, caused by a lighted candle, during the height of the storm resulted in 47 deaths. Minor damage occurred at Clark AB with a roof blown from a school building and falling trees causing other damage. One ship was reported sunk while another went aground as Kim exited into the South China Sea.

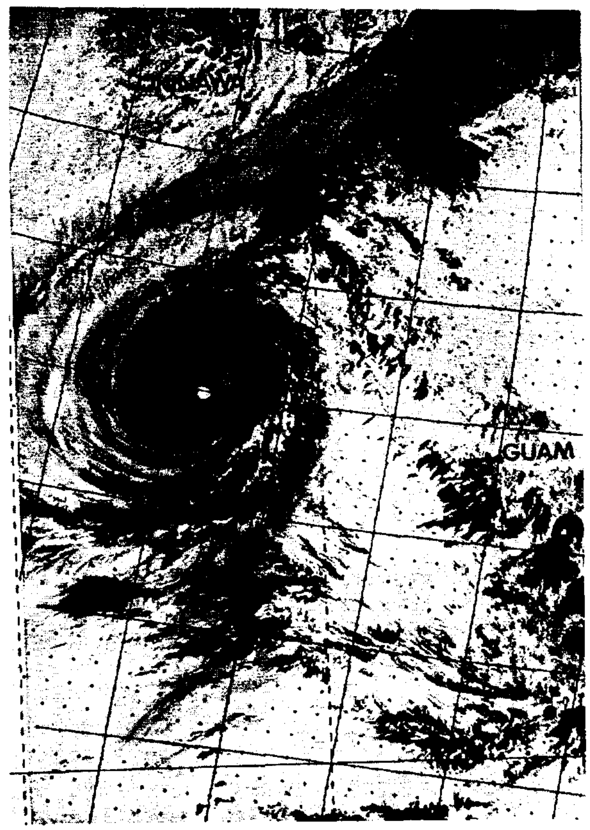


FIGURE 4-28. Infrared photograph of Typhoon Kim at peak intensity of 125 kt (64 m/sec), 10 November 1977, 2145Z. (DMSP imagery)

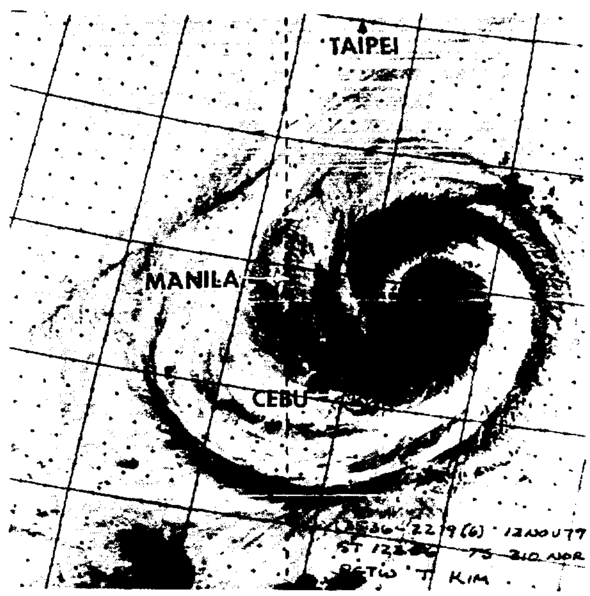
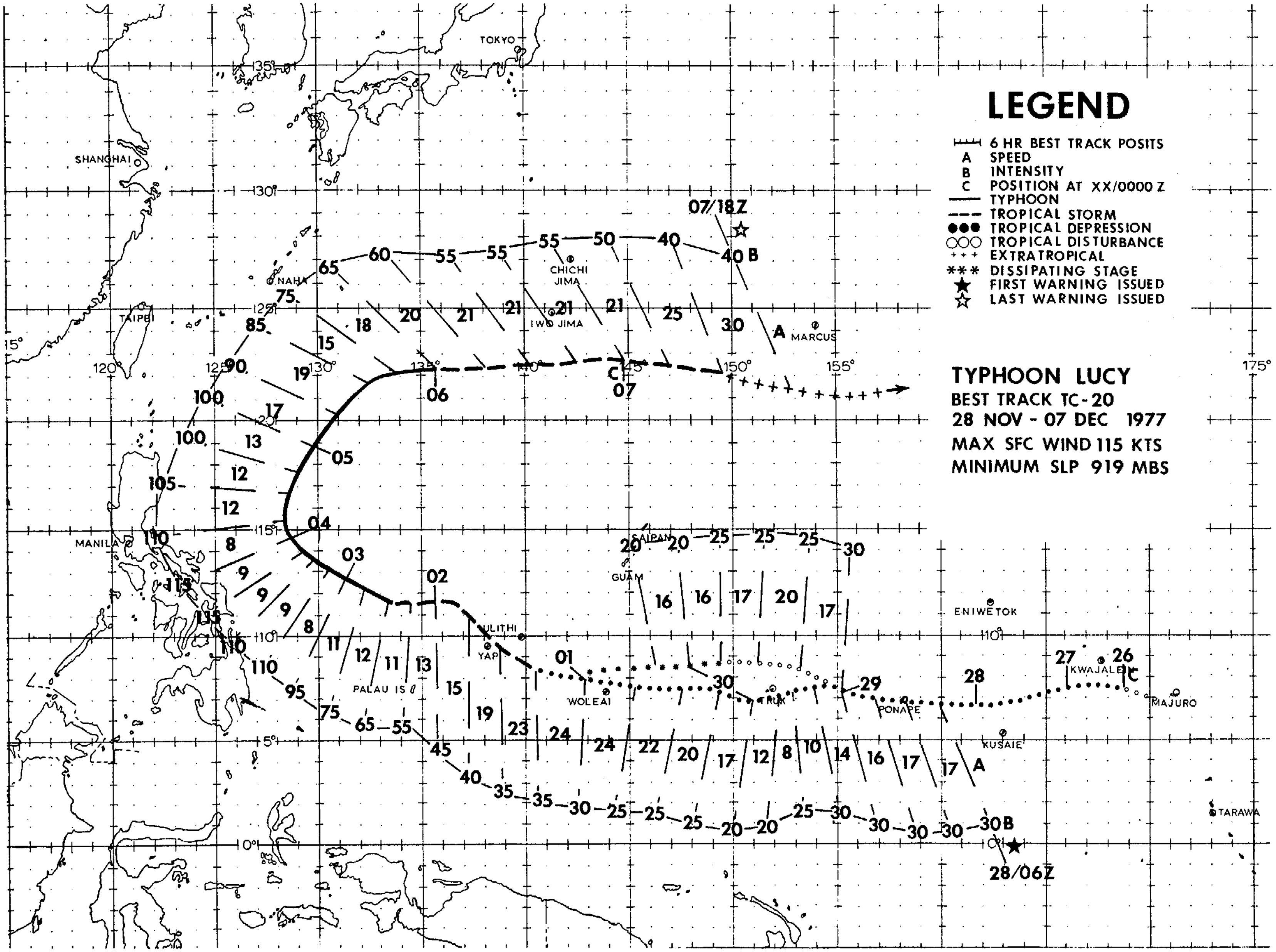


FIGURE 4-29. Infrared photograph of Typhoon Kim with 110 kt (57 m/sec) winds about 20 hours before landfall on the Philippine Islands, 12 November 1977, 2255Z. (DMSP imagery)


LEGEND
6 HR BEST TRACK POSITS
A SPEED
B INTENSITY
C POSITION AT XX/0000 Z
TYPHOON
TROPICAL STORM
TROPICAL DEPRESSION
TROPICAL DISTURBANCE
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
TYPHOON LUCY
BEST TRACK TC-20
28 NOV - 07 DEC 1977
MAX SFC WIND 115 KTS
MINIMUM SLP 919 MBS
07/18Z
28/06Z
TOKYO
SHANGHAI
NAHA
TAIPEI
CHICHI JIMA
IWO JIMA
MARCUS
MANILA
SAIPAN
GUAM
ULITHI
YAP
PALAU IS
WOLEAI
TRUK
PONAPE
ENIWETOK
KWAJALEIN
MAJURO
KUSAIE
TARAWA

Lucy, the 10th typhoon, was in most respects a typical winter season storm. Development was difficult and near the equator while recurvature occurred at a low latitude. An unusual event happened during the development stage when the system divided into two disturbances and then recombined 2 days later.

As with the previous typhoon (Kim), Lucy's birth was a "double vortice" development pattern discussed by many authors. The earliest accounts of tropical storms occurring simultaneously on both sides of the equator are described in a book "The Law of Storms" by Reid (1849). In this particular case the tropical cyclone in the Southern Hemisphere near equatorial trough (NET) developed first and was well on its way to maturity before Lucy formed in the Northern Hemisphere NET. The expanding circulation about the Southern Hemisphere TC 24-77 (Steve) strengthened the westerly flow along the equator increasing the horizontal shear along the Northern Hemisphere NET aiding the development of Lucy (Fig. 4-30). On the 26th, 33 kt (17 m/sec) gradient level winds were observed at Tarawa (WMO 91610), an island about 75 nm (139 km) north of the equator. Westerlies extended above 500 mb and created an extensive horizontal wind shear trough north of the equator. Enough cyclonic spin was imparted over the Marshall Island area that the nearby preexisting disturbance began to develop. All factors for further development were present therefore, at 270600Z a Tropical Cyclone Formation Alert was issued.

A large mid-tropospheric anticyclone dominated the subtropical western Pacific and concentrated strong trade winds north of the depression. The system soon began accelerating westward as it neared the anticyclone's southern domain. Synoptic data indicated an increase in circulation size and satellite imagery showed better organization. Weather reconnaissance aircraft were sent in to investigate further. Early on the 28th aircraft found a 997 mb surface pressure center with 30 kt (15 m/sec) surface winds and 45 kt (23 m/sec) flight level winds at 1500 ft (457 m). JTWC thus issued their first warning on TD 20 at 280600Z. Six hours later the depression crossed the southern coast of Ponape (WMO 91348) with only 10 kt (5 m/sec) sustained and 25 kt (13 m/sec) gusts reported. These unexpectedly weak surface winds supported prior aircraft reports which observed maximum winds at flight level, not surface.

On the 29th TD 20 split into two disturbances. One went northwestward and the other west-southwest around the Truk Islands (Fig. 4-31). This split occurred when increasing amplitudes in the mid-latitude long wave patterns strengthened the subtropical, mid-tropospheric anticyclone which was positioned north of TD 20. The pressure gradient between TD 20 and the high pressure cell generated 45 kt (23 m/sec) easterly flow at 500 mb. The resulting intense, horizontal shear produced enough vorticity to induce a secondary circulation system just north of TD 20. As they separated, both systems weakened as their energy sources also became divided.

Because the northern system was generated in the mid-troposphere, it was reflected on the surface only as a weak depression. Infrared satellite imagery identified the northern split as having more activity at higher levels. Aircraft and synoptic data indicated better organization in the southern split. The northern system reached a maximum forward speed of 20 kt (37 km/hr) as the pressure gradient peaked. This rapid movement

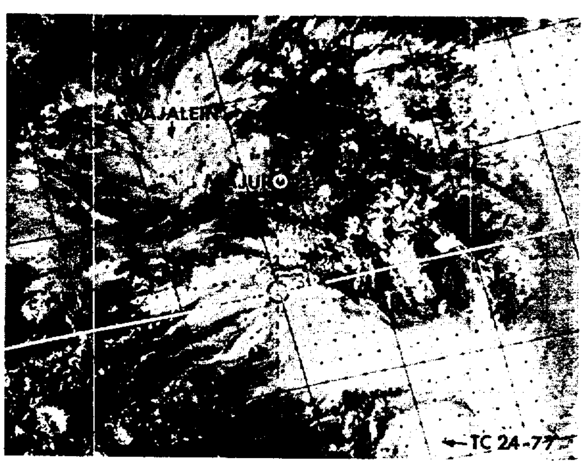


FIGURE 4-30. "Double Vortices". Lucy is seen in her formative stage in the Northern Hemisphere NET between Kwajalein and Majuro while TC 24-77 (Steve) is near maturity in the Southern Hemisphere NET, 25 November 1977, 2118Z. (NOAA-5 imagery)

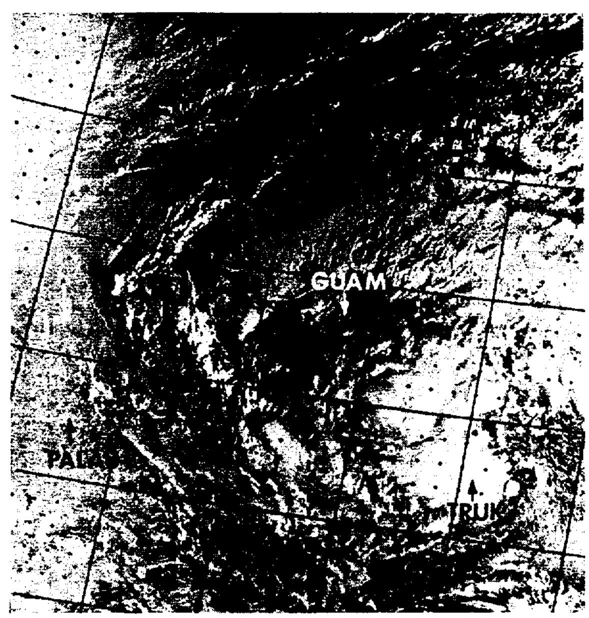


FIGURE 4-31. Lucy during an unusual split configuration while over the Caroline Islands, 29 November 1977, 2125Z. (DMSP imagery)

placed the secondary disturbance well ahead of TD 20's primary circulation. As the dual system moved westward away from the dominating influence of the subtropical high, horizontal shear and induced vorticity diminished. This resulted in the northern system's deceleration and dissipation. The southern, primary, system soon caught up to and absorbed the remnants of the northern system 100 nm (185 km) northwest of Woleai Atoll. By 0000Z on the 1st of December, TD 20 was again a single system with the same intensity as it was before the split.

TD 20 now began heading northwestward around the southwestern periphery of the steering anticyclone toward a break in the subtropical ridge. Deceleration and intensification progressed for the next 2 days. TD 20 became Tropical Storm Lucy at 010600Z. Aircraft data, however, still indicated that the storm was best developed in the middle layers. This was again evidenced when Lucy passed 25 nm (46 km) northwest of Yap (WMO 91413) which only experienced 15 kt (8 m/sec) sustained surface winds and a sea-level pressure minimum of 1001 mb.

Continuing northwestward, Lucy appeared to be heading for a recurvature path. An intense, short-wave trough was passing north of Lucy, with an apparent weakening in the subtropical ridge. But the trough quickly passed, trailing a migratory anticyclone behind and Lucy again took a more westward track. Now headed for the Republic of the Philippines, Lucy attained typhoon intensity at 020600Z and continued to deepen. Synoptic and satellite data showed excellent upper level divergence in all quadrants. Aircraft reconnaissance began reporting maximum winds nearer the surface, indicating better vertical development. By this time Lucy attained a maximum intensification rate of 20 kt (10 m/sec) per 6 hours and satellite data revealed a large, well defined eye (Fig. 4-32).

By the 3rd of December, Lucy was again heading northwestward as a strong westerly trough began creating another weakness in the subtropical ridge. In 24 hours the ridge west of Lucy had completely dissipated. Lucy's easterly steering currents rapidly weakened under increasing pressure from the advancing trough. At 1800Z on the 3rd, a 115 kt (59 m/sec) maximum intensity was reached with a minimum forward speed of 8 kt (15 km/hr). Within the next 12 hours, Lucy recurved ahead of the approaching trough.

The storm soon became completely embedded in mid-latitude westerly flow and accelerated northeastward. Lucy was downgraded to tropical storm stage 48 hours after recurvature. Upper level vertical shear and low level cool, dry entrainment became the significant factors for weakening. Lucy was eventually steered into a frontal zone and became an extratropical wave within the boundary.

The last warning was issued at 071800Z. Lucy's extratropical transformation extended over several days since both polar and tropical air flows converged into the system. Lucy traveled eastward as a weak cyclone along the front and was eventually absorbed into a large, winter storm system over the central Pacific.

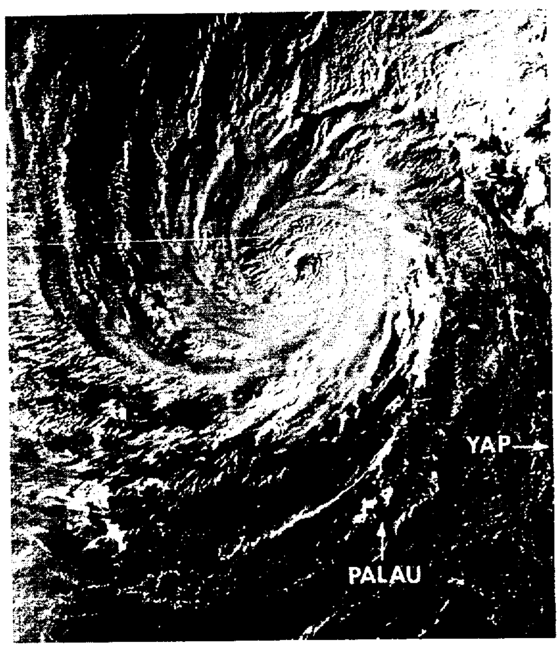
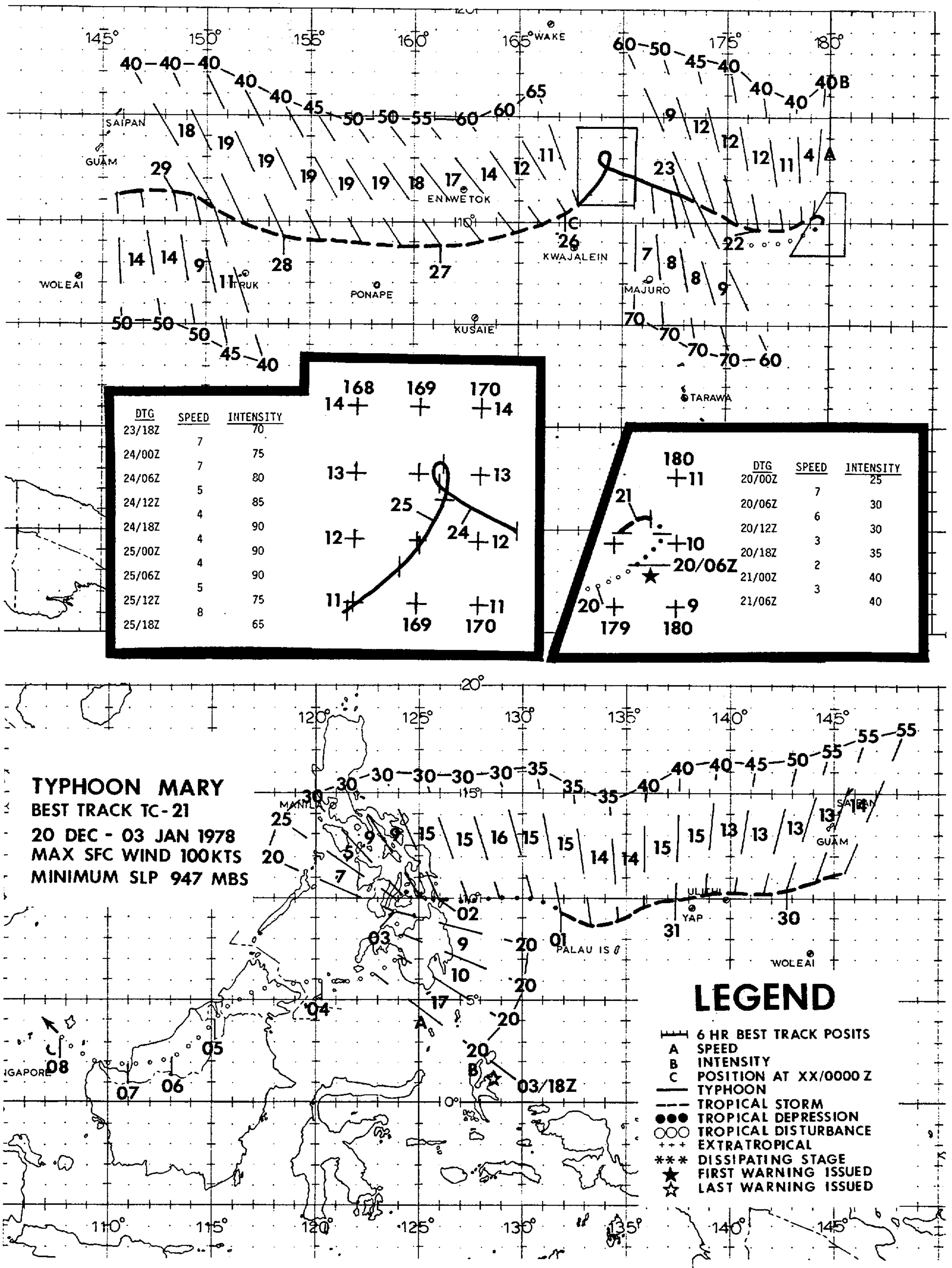


FIGURE 4-32. Typhoon Lucy with 85 kt (44 m/sec) winds and undergoing rapid deepening, 2 December 1977, 2215Z. (DMSP imagery)


TYPHOON MARY
BEST TRACK TC-21
20 DEC - 03 JAN 1978
MAX SFC WIND 100KTS
MINIMUM SLP 947 MBS
DTG SPEED INTENSITY
23/18Z 70
24/00Z 7 75
24/06Z 7 80
24/12Z 5 85
24/18Z 4 90
25/00Z 4 90
25/06Z 4 90
25/12Z 5 75
25/18Z 8 65
DTG SPEED INTENSITY
20/00Z 25
20/06Z 7 30
20/12Z 6 30
20/18Z 3 35
21/00Z 2 40
21/06Z 3 40
20/06Z
03/18Z
SAIPAN
GUAM
WAKE
ENIWETOK
KWAJALEIN
WOLEAI
TRUK
PONAPE
KUSAIE
MAJURO
TARAWA
MANILA
PALAU IS
YAP
ULITHI
LEGEND
6 HR BEST TRACK POSITS
A SPEED
B INTENSITY
C POSITION AT XX/0000 Z
TYPHOON
TROPICAL STORM
TROPICAL DEPRESSION
TROPICAL DISTURBANCE
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED

Mary, the 11th and final typhoon of the year moved across the western Pacific for 15 days and covered 4002 nm (7445 km), the second longest storm on record for distance traveled. On the 19th of December satellite data detected a tropical disturbance moving slowly east-northeastward near 9N-177E where weak steering currents existed. Steering was primarily influenced by the winter season westerlies, which extended far into the subtropics. During the next few hours, satellite data indicated slow intensification while a well defined comma shaped cloud was becoming evident (Fig. 4-33). At 0000Z on the 20th a formation alert was issued. Upper air data at 500 mb indicated that a strong mid-tropospheric subtropical ridge had formed to the west of the disturbance. At the same time an intense mid-latitude 500 mb trough was approaching. The combined effects of this trough and a strong anticyclone above the storm produced steady upper level divergence and created a well defined outflow channel to the north. Further intensification appeared likely and the first warning was issued on TD 21 at 0600Z on the 20th. However, for the next 24 hours, the system became quasi-stationary near 10N-179E as the westerlies gradually receded northward. During this period the system grew to tropical storm strength as GOES imagery indicated increased outflow to the north.

Shortly after 1200Z on the 21st, the storm began to accelerate westward. The 500 mb trough to the north had moved eastward with a ridge now developing north of Mary. This formation imparted westerly steering flow south of the ridge axis. Mary responded and quickly accelerated to 12 kt (22 km/hr). On the 22nd Mary turned toward the west-northwest in response to a shallow mid-latitude trough which weakened the subtropical ridge northwest of the storm. By 0000Z on the 23rd Mary reached typhoon intensity as satellite data indicated continued increase in outflow and formation of an eye. Mary slowed to 8 kt (15 km/hr) and continued moving west-northwest for the next 30 hours while intensifying further.

The first aircraft reconnaissance entered the storm at 0115Z on the 24th and reported 90 kt (46 m/sec) maximum surface winds and 75 kt (39 m/sec) winds at 700 mb. Satellite data also estimated the storm intensity to be 75 kt (39 m/sec). About five hours later, Mary began to decelerate while nearing a weakness in the subtropical ridge. Then the storm turned northward and appeared as though recurvature was beginning. However, analysis of 500 mb synoptic data indicated the mid-latitude westerlies were again receding. The subtropical ridge again reestablished itself and Mary responded by looping clockwise and was subsequently influenced by the northerly flow around the eastern edge of a strong, eastward migrating anticyclone. The storm now moved south-southwestward at 5 kt (9 km/hr). Satellite data (Fig. 4-34) indicated Mary had continued to intensify and at 0314Z on the 25th aircraft reconnaissance indicated a central pressure of 947 mb with maximum sustained surface winds of 100 kt (51 m/sec). Just three hours later, Utirik Atoll 55 nm (102 km) southeast of Mary, recorded winds of 40 kt (21 m/sec).

Mary soon began to accelerate to 12 kt (22 km/hr) towards the west-southwest along the southeastern periphery of the strengthening subtropical high cell. The resulting steering flow at mid-levels plus rapid movement of the typhoon were expected to weaken Mary. By the 26th satellite data indicated

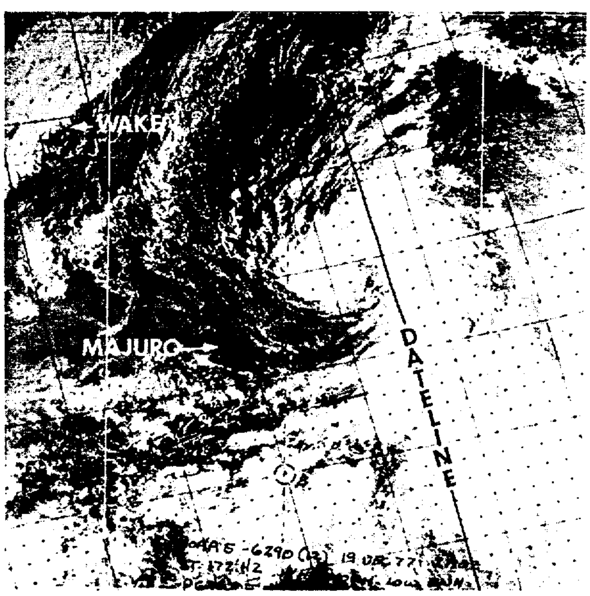


FIGURE 4-33. *Mary during initial development near the dateline, 19 December 1977, 2110Z. (NOAA-5 imagery)*

Mary had indeed weakened and Mary was downgraded to a tropical storm. Aircraft reconnaissance at 0357Z on the 26th confirmed corresponding satellite data when 60 kt (31 m/sec) surface winds were observed.

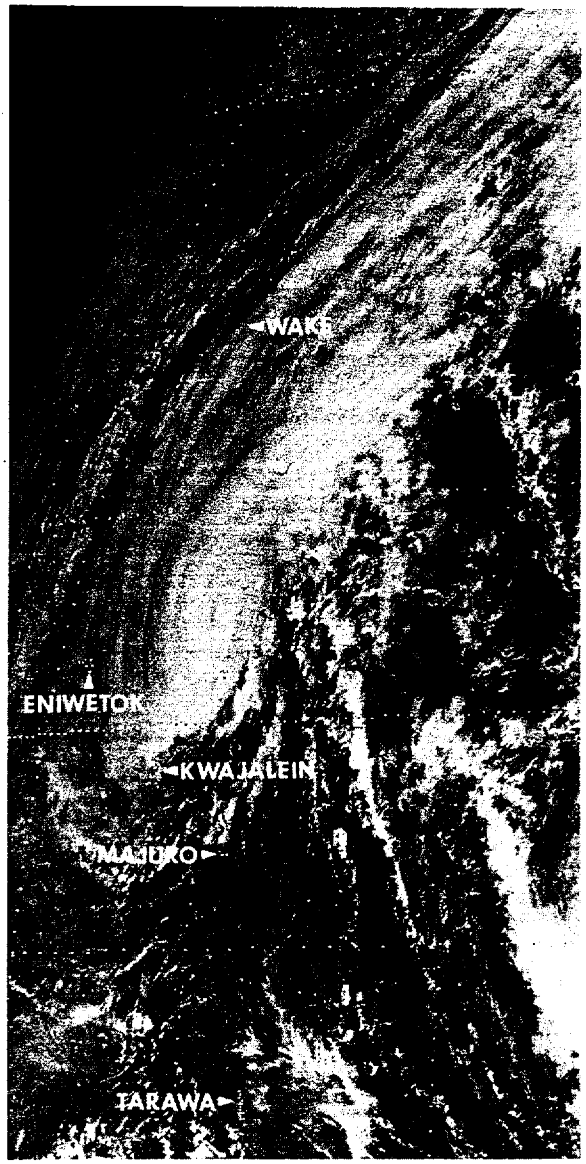


FIGURE 4-34. Typhoon Mary during execution of a loop 6 hours before attaining a maximum 100 kt (51 m/sec) intensity, 24 December 1977, 2049Z. (GOES imagery from SFSS, Honolulu, HI)

As Mary turned westward along the southern boundary of the subtropical high cell, the storm accelerated to 19 kt (35 km/hr). By the 28th Mary began moving west-northwestward in response to another trough induced weakness in the subtropical ridge. Mary again slowed due to the weaker steering currents. Satellite data once again indicated intensification (Fig. 4-35). As the trough moved rapidly eastward, the subtropical ridge again strengthened north of the storm and Mary turned west-southwestward and began to weaken for the second time. Accelerating steadily Mary attained a 15 kt (28 km/hr) forward movement and continued to weaken as development became restricted by the expanding ridge.

Mary continued her westward movement for the next several days. Weakening slowly, the storm was downgraded to a tropical depression at 0000Z on the 1st of January. The system maintained 30 kt (15 m/sec) winds until moving over the central Philippines near Leyte Gulf. Satellite data indicated rapid dissipation over land with the final warning issued at 1800Z on the 3rd. Mary turned sharply southward over the Philippines when the strong northeast monsoon was encountered, which aided rapid dissipation.

Although Mary was not the longest lived storm on record, the 4002 nm (7445 km) distance traveled was the second longest. What is also noteworthy is that no injuries or major damage resulted during its long journey across the western Pacific. Mary was indeed a fitting end to a most unusual tropical cyclone year.

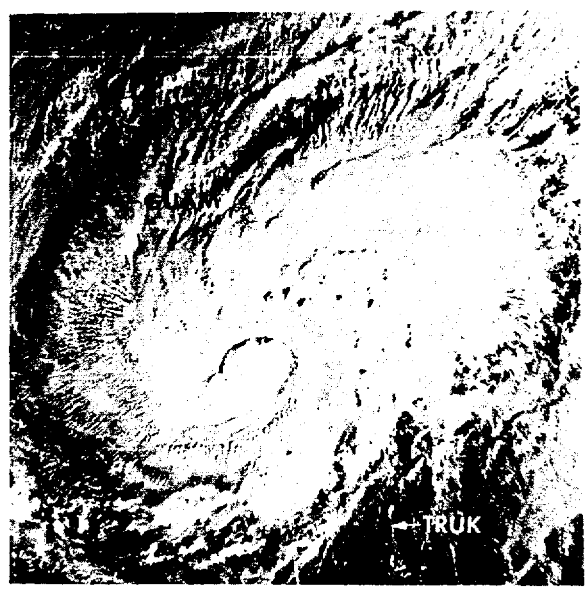


FIGURE 4-35. Mary at 50 kt (26 m/sec) intensity and slowly deepening between Guam and Truk, 28 December 1977, 2136Z. (DMSP imagery)

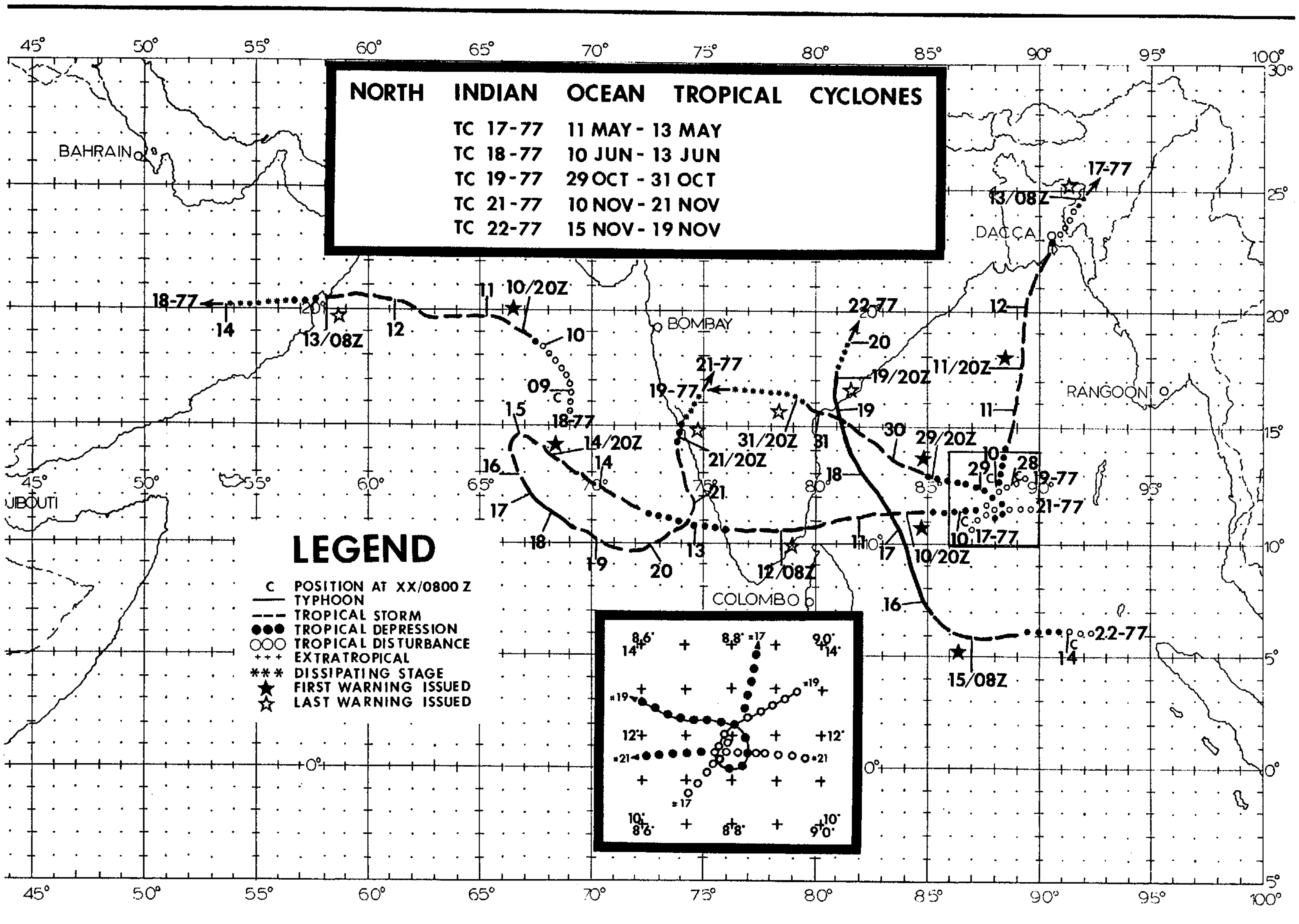
2. NORTH INDIAN OCEAN TROPICAL CYCLONES

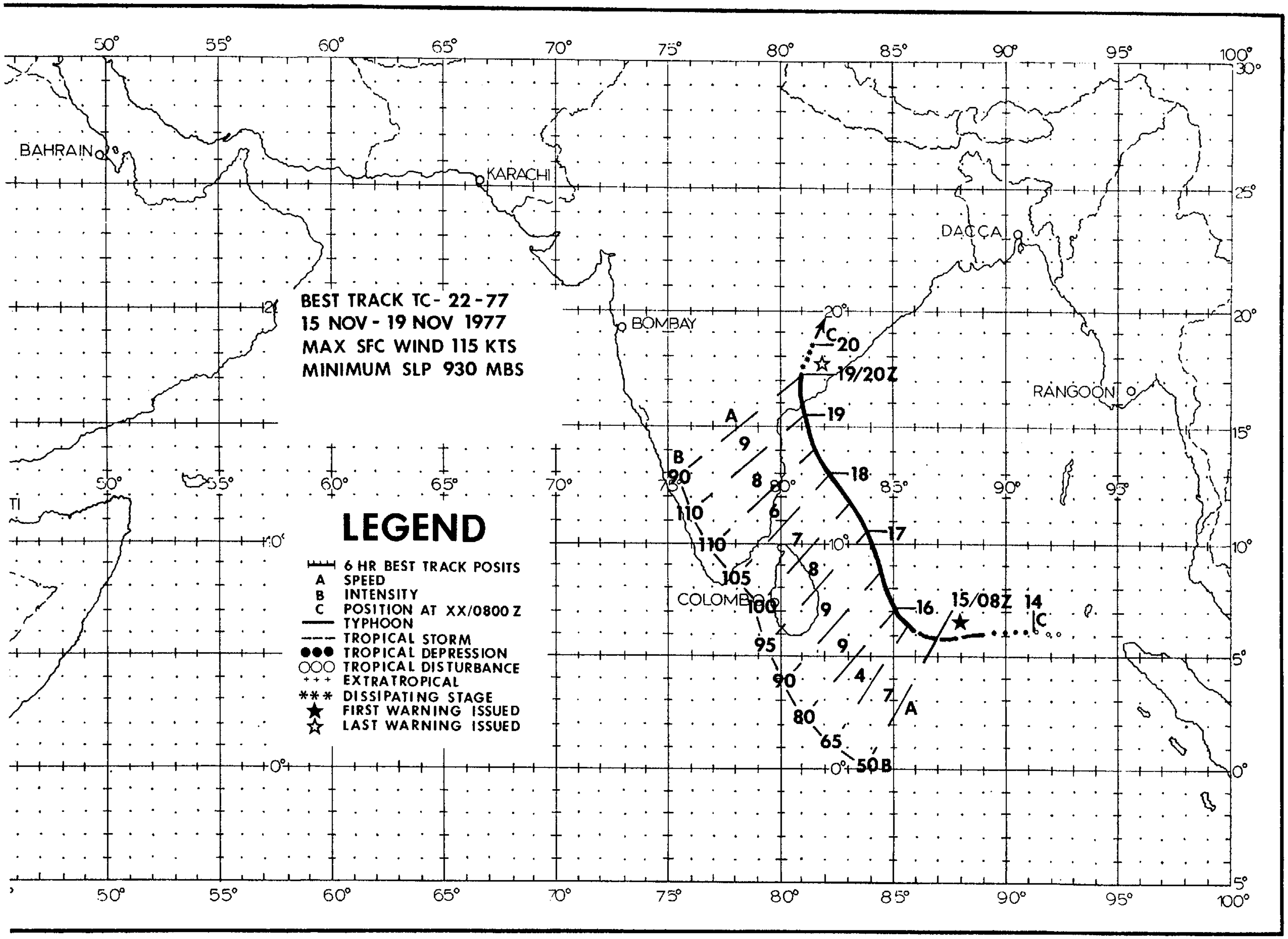
During 1977, there were five tropical cyclones in the North Indian Ocean (Table 4-6). These occurrences were climatologically consistent; two in the spring and three in the autumn. However, these cyclones persisted much longer and were more intense than normal. TC 21-77, for example, developed in the Bay of Bengal, traversed southern India, regenerated in the Arabian Sea, looped while reaching typhoon strength, then finally dissipated over southwestern India after traveling a total of 1387 nm (2570 km). TC 22-77 was the next and largest cyclone this season. It became the third and most destructive storm to hit India. Because of its strength and devastating impact, TC 22-77 is further discussed in the following individual summary.

TABLE 4-6. FREQUENCY OF NORTH INDIAN OCEAN CYCLONES BY MONTH AND YEAR.

YEAR*	J	F	M	A	M	J	J	A	S	O	N	D	TOTAL
1971	0	0	0	0	0	0	0	0	0	1	1	0	2
1972	0	0	0	1	0	0	0	0	2	0	1	0	4
1973	0	0	0	0	0	0	0	0	0	1	2	1	4
1974	0	0	0	0	0	0	0	0	0	0	1	0	1
1975	1	0	0	0	2	0	0	0	0	1	2	0	6
1976	0	0	0	1	0	1	0	0	1	1	0	1	5
1977	0	0	0	0	1	1	0	0	0	1	2	0	5
AVG	0.1	0	0	0.3	0.4	0.3	0	0	0.4	0.7	1.3	0.3	3.9

*1971-1974 REPRESENT BAY OF BENGAL CYCLONES ONLY


NORTH INDIAN OCEAN TROPICAL CYCLONES
TC 17-77 11 MAY - 13 MAY
TC 18-77 10 JUN - 13 JUN
TC 19-77 29 OCT - 31 OCT
TC 21-77 10 NOV - 21 NOV
TC 22-77 15 NOV - 19 NOV
LEGEND
C POSITION AT XX/0800 Z
TYPHOON
TROPICAL STORM
TROPICAL DEPRESSION
TROPICAL DISTURBANCE
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
BAHRAIN
DJIBOUTI
BOMBAY
COLOMBO
DACCA
RANGOON
18-77
17-77
19-77
21-77
22-77
10/20Z
13/08Z
14/20Z
21/20Z
31/20Z
19/20Z
11/20Z
29/20Z
10/20Z
12/08Z
15/08Z


BEST TRACK TC- 22-77
15 NOV - 19 NOV 1977
MAX SFC WIND 115 KTS
MINIMUM SLP 930 MBS
LEGEND
6 HR BEST TRACK POSITS
A SPEED
B INTENSITY
C POSITION AT XX/0800 Z
TYPHOON
TROPICAL STORM
TROPICAL DEPRESSION
TROPICAL DISTURBANCE
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
BAHRAIN
KARACHI
BOMBAY
DACCA
RANGOON
COLOMBO
15/08Z
19/20Z
50°
55°
60°
65°
70°
75°
80°
85°
90°
95°
100°
30°
25°
20°
15°
10°
5°
0°

NEW 2-76)

TC 22-77 was the most devastating storm in the Indian Ocean since 1971. It developed 115 kt (59 m/sec) winds and inundated Southeastern India with heavy rains and high seas. TC 22-77 occurred during the autumn monsoon transition period, when cyclone development is most favorable, and became the only storm to attain typhoon strength this season in the Bay of Bengal.

Meteorological satellite first located TC 22-77 during the morning of the 14th of November as a weak disturbance, approximately 150 nm (278 km) southwest of the Nicobar Islands. Five hours later new satellite data revealed better defined banding which indicated increased organization. This prompted the issuance of a formation alert the same day at 1310Z. Heading due west along the southern periphery of the mid-tropospheric subtropical ridge, the disturbance quickly accelerated to 13 kt (24 km/hr), while steadily intensifying. Later satellite and synoptic data supported a well developed cyclone of about 40 kt (21 m/sec). At 0800Z on the 15th the first warning was issued. A post analysis showed that TC 22-77 was rapidly developing during this period.

Ever since TC 22-77 was first detected, an upper tropospheric trough was forming over northern India. By the 15th this trough was firmly established and extended over central India, creating a break in the subtropical ridge. As the cyclone neared India, it began moving northwestward toward the trough induced break. This break also weakened the mid-tropospheric anticyclone and consequently reduced the storm's steering flow, and as a result, TC 22-77 steadily slowed to a 4 kt (7 km/hr) movement. It was now intensifying at the rate of 30 kt (15 m/sec) per 24 hours, primarily in response to the divergent southwesterly flow produced by the upper level trough above the approaching cyclone. TC 22-77 attained typhoon strength by the afternoon of the 15th, and by 0629Z on the 16th satellite data revealed an eye.

For the next 2 days, TC 22-77 tracked north-northwestward at an average speed of 9 kt (17 km/hr) while continuing to strengthen. By the 18th, it began to decelerate and was intensifying 10 kt (5 m/sec) each day. Successive satellite pictures showed tighter banding features while the eye became more distinct (Fig. 4-36). Approximately 75 nm (140 km) from the Indian coast, TC 22-77 reached a maximum intensity of 115 kt (59 m/sec). Just prior to landfall, TC 22-77 accelerated to 9 kt (17 km/hr) toward the north-northwest. At 1100Z on the 19th, the storm struck with sustained winds of 105 kt (54 m/sec) and an 18 ft (5.5 m) tidal wave along the coast of Andhra Pradesh about 40 nm (75 km) south of Vijayawada (WMO 43181). TC 22-77 then turned northward over flat farm lands while weakening slowly, and the final warning was issued at 2000Z on the 19th.

The combined winds, seas and rains generated by TC 22-77 killed nearly 10,000 people, left hundreds of thousands homeless and devastated lands that produce roughly 40 per cent of India's food grains. The tidal wave was probably the single most destructive force accompanying the storm. It penetrated 10 nm (19 km) inland and washed away more than 21 villages.

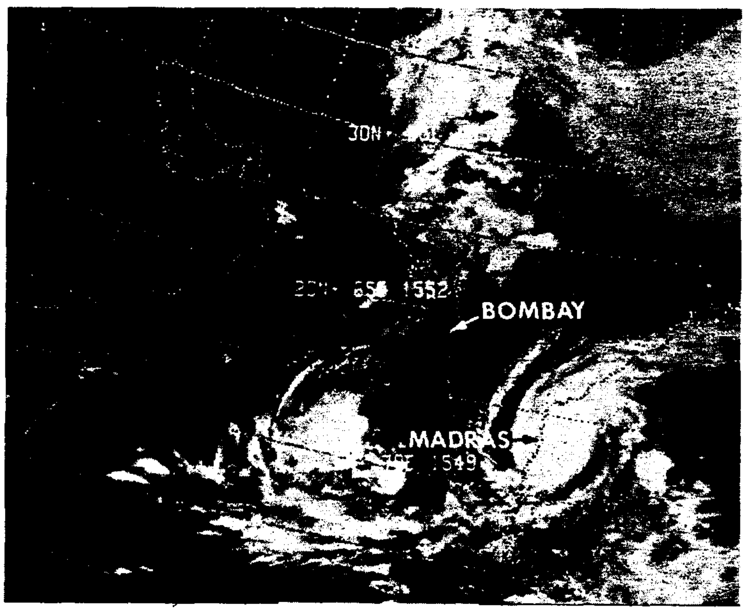


FIGURE 4-36. Infrared photograph of TC 22-77 at maximum intensity of 115 kt (59 m/sec), 18 November 1977, 1618Z. In the Arabian Sea TC 21-77 with 65 kt (33 m/sec) winds completing a loop before striking southwestern India. (NOAA-5 imagery from FLEWEAFAC Suitland, MD)

3. CENTRAL NORTH PACIFIC TROPICAL CYCLONES

No tropical cyclones developed over the central North Pacific during 1977 (Table 4-7).

TABLE 4-7. FREQUENCY OF CENTRAL PACIFIC STORMS BY MONTH AND YEAR. (NUMBER IN PARENTHESIS INDICATE STORMS REACHING HURRICANE INTENSITY)

	JAN-JUN	JUL	AUG	SEP	OCT	NOV-DEC
1967	0	0	0	0	1	0
1968	0	0	2	0	0	0
1969	0	0	0	0	0	0
1970	0	0	1	0	0	0
1971	0	1 (1)	1	0	0	0
1972	0	0	3 (1)	1	0	0
1973	0	1 (1)	0	0	0	0
1974	0	0	2 (1)	0	0	0
1975	0	0	0	0	0	0
1976	0	0	0	1 (1)	0	0
1977	0	0	0	0	0	0
AVERAGE	0	.2(.2)	.8(.2)	.2(.1)	.1	0